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IEEE Std 3007.3™-2012

Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

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IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

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IEEE-SA Standards Board

Abstract: All aspects of electrical safety in industrial and commercial power systems are covered. This recommended practice provides personnel with guidelines for understanding the fundamental concepts of the hazards of electricity along with safety-related activities associated with the operation and maintenance of in-plant electrical power distribution systems.

Keywords: electrical hazards, electrical safety program, electrical safety-related maintenance, fire protection, grounding, IEEE 3007.3, personal protective equipment, safe electrical work practices, safety single-line diagram

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Introduction

This introduction is not part of IEEE Std 3007.3-2012, IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems.

IEEE Std 902™-1998 [B27], also known as the *IEEE Yellow Book*™, has been an excellent resource for engineering, management, safety professionals, and maintenance personnel since it was published.[a] The entire IEEE Color Books® series is in the process of being revised and reorganized into numerous "dot" standards, under the 3000 series of standards, with the *IEEE Yellow Book* being divided into three such "dot" standards. The new "dot" standards for operations and management, maintenance, and safety are as follows:

— IEEE Std 3007.1™-2010 [B29]

— IEEE Std 3007.2™-2010 [B30]

— IEEE Std 3007.3™-2012 (this standard)

IEEE Color Book reorganization

The thirteen recommended practices, known as the *IEEE Color Books*, have been industry-proven tools specifically developed for engineers, involved in all facets of industrial and commercial power systems, for many years. This set of recommended practices covers the many varied subjects dealing with all aspects of industrial and commercial power systems, including: analyzing, planning, calculating, coordinating, protecting, and assuring the safety of the power systems elements, equipment, and systems.

In 2002, the Industrial and Commercial Power Systems (I&CPS) Department of the Industry Applications Society (IAS) and the IEEE Standards Association (SA) initiated a major project to reorganize the IEEE Color Books series of standards. The primary goal of the project is to split up the recommended practices into a series of "dot" standards, such as IEEE Std 3007.1-2010 [B29], to allow each technical topic to be developed and balloted individually. A secondary goal of the project is to eliminate duplicate material that presently exists in the Color Book standards.

The decision to reorganize the Color Books standards was largely driven by the difficulty that exists today to review, revise, and ballot large standards (the "books") in a timely manner. Technical material presented in smaller documents (via "dot" standards) can be more effectively and efficiently managed, and will facilitate more frequent updating.

The thirteen Color Books standards are being reorganized into a larger introductory book (the "base" book), plus approximately 60 individual "dot" standards covering various technical topics.

Much of the general power-systems information will be assembled into the new "base" book that will serve as a launching point to jump into the more detailed specifics of industrial and commercial power systems. Working Group subject matter experts are providing and maintaining the technical content and are focused on those areas that are changing with new technologies, while allowing the more basic areas to remain stable.

IEEE Std 3007.3-2012 provides a recommended practice for electrical safety of industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience in this area. It can also be an aid to all engineers responsible for the operation and maintenance of industrial and commercial power systems.

[a] The numbers in brackets correspond to those of the bibliography in Annex A.

Due to the vital importance of electrical safety when working with industrial and commercial power systems, IEEE Std 3007.3-2012 provides more in-depth information to help ensure the safety of personnel working with electrical systems and equipment.

This standard is organized as follows:

Clause 1: Overview

Clause 2: Normative references

Clause 3: Definitions, acronyms, and abbreviations

Clause 4: Introduction to electrical safety

Clause 5: Establishing an electrical safety program

Clause 6: Providing and maintaining electrically safe facilities

Clause 7: Safe electrical work practices

Clause 8: Protective equipment, tools, and methods

Clause 9: Safety of use of electrical equipment

The new IEEE Std 3007.3-2012 provides a recommended practice for electrical safety of industrial and commercial power systems.

Contents

IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

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1. Overview

1.1 Scope

This recommended practice covers all aspects of electrical safety in industrial and commercial power systems. It provides personnel with guidelines for understanding the fundamental concepts of the hazards of electricity along with safety-related activities associated with the operation and maintenance of in-plant electrical power distribution systems.

1.2 General

An electrical safety program should address the needs of all employees, contractors, and visitors present at a facility. The size of the program depends upon the size and nature of the company, both in the number and complexity of facilities, and the number of personnel involved with electrical work. The guidance in this recommended practice presents the overall picture and expects that companies will consider their own specific needs. The program should be as simple and easy to understand as possible. At the same time, however, it should cover all the needs of each member of the organization.

An electrical safety program should define its objectives. The program objectives should consider the following:

a) To familiarize workers with the details of each procedure associated with the intended task

b) To familiarize workers with individual rights and responsibilities associated with the intended task

c) To demonstrate the employer's intention to provide a safe working environment

d) To document general requirements and guidelines intended to eliminate unauthorized exposure to electrical hazards

e) To direct the activities of workers who could be exposed to an electrical hazard

f) To enable each employee to take responsibility for his or her own safety through self-discipline

The electrical safety program should be formal, written, published, and available to all workers. The documented electrical safety program provides an indication that an employer intends to comply with regulatory requirements when requested to do so.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Accredited Standards Committee C2, National Electrical Safety Code® (NESC®).[1]

ANSI/ASSE Z244.1, Control of Hazardous Energy—Lockout/Tagout and Alternative Methods.[2]

ANSI/NEMA Z535.5, Safety tags and barricade tapes (for temporary hazards).[3]

ASTM F855, Standard Specifications for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment.[4]

Code of Federal Regulations Title 29 Part 1910 (29CFR1910), Occupational Safety and Health Standards.[5]

Code of Federal Regulations Title 29 Part 1926 (29CFR1926), Safety and Health Regulations for Construction.

EN 50110-1,-2, Operation of electrical installations.[6]

IEEE Std 80™, IEEE Guide for Safety in AC Substation Grounding.[7, 8]

IEEE Std 1584™, IEEE Guide for Performing Arc-Flash Hazard Calculations.

IESNA Lighting Handbook.[9]

[1] The NESC is available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/).
[2] ANSI publications are available from the American National Standards Institute (http://www.ansi.org/).
[3] NEMA publications are available from Global Engineering Documents (http://global.ihs.com/).
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NFPA 70®, National Electrical Code® (NEC®).[10]

NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.[11]

NFPA 70E®, Standard for Electrical Safety in the Workplace.

Parise, G., Moylan, W., and Sutherland, P. E., "Electrical safety for employee workplaces in Europe and in USA," *IEEE Transactions on Industry Applications,* vol. 41, no. 4, July/August 2005.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

IEEE Standards Dictionary: Glossary of Terms and Definitions [B20] should be consulted for terms not defined in this clause. [12, 13]

3.2 Acronyms and abbreviations

ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CPR	cardiopulmonary resuscitation
D-N	Drouet-Nadeau
GFCI	ground fault circuit interrupter
IESNA	Illuminating Engineering Society of North America
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NRTL	nationally recognized testing laboratory
OSHA	Occupational Health and Safety Administration
PPE	personal protective equipment
UL	Underwriters Laboratories

[10] The NEC is published by the National Fire Protection Association (http://www.nfpa.org/). It is also available from the IEEE at http://www.techstreet.com/ieeegate.html.
[11] NFPA publications are available from the National Fire Protection Association (http://www.nfpa.org/).
[12] *IEEE Standards Dictionary: Glossary of Terms and Definitions* is available at http://shop.ieee.org.
[13] The numbers in brackets correspond to those of the bibliography in Annex A.

4. Introduction to electrical safety

4.1 General discussion

NFPA 70E-2009 defines an electrical hazard as "a dangerous condition such that contact or equipment failure can result in electric shock, arc-flash burn, thermal burn, or blast."[14] Electrical safety is defined as "recognizing hazards associated with the use of electrical energy and taking precautions so that hazards do not cause injury or death."

Some explanation is necessary to fully appreciate the words of the two definitions. Personnel should understand the nature and consequences of electrical hazards and the reasons for practicing electrical safety. The nature of electrical hazards is discussed in 4.2. The consequences are demonstrated by some true case histories of injuries, deaths, and near-misses, as described in 4.3. Finally, 4.4 discusses the reasons for spending money and effort on electrical safety.

It is important to understand the four main phases of protection from electrical hazards.

a) First, unless de-energizing is infeasible due to the nature of the task or creates a more hazardous situation, potentially energized electrical conductors and circuit parts must be placed in an electrically safe work condition before personnel work within the *limited approach boundary*. Safe practices must be used to establish an electrically safe work condition. An electrically safe work condition is discussed in Clause 7.

b) Second, electrical installations should be designed and constructed to be safe by complying with the criteria as stipulated in national and international consensus standards and codes. This subject is discussed in Clause 6.

c) Third, the integrity of electrical equipment must be maintained with particular emphasis on enclosures, insulation, operating mechanisms, grounding, and circuit protective devices. Maintenance is discussed in IEEE Std 3007.2™-2010 [B30], as well as in Clause 6.

d) Fourth, safe work practices and adequate protective equipment, insulated and insulating tools, and test equipment must be understood and used when working on or near exposed energized conductors or parts of electrical equipment. Safe practices are covered in Clause 7. Personal protective equipment (PPE), appropriate tools, and other protective methods are discussed in Clause 8. The safety of use of electrical equipment is discussed in Clause 9.

The details of the above concepts should be implemented and documented into a cohesive electrical safety program. Clause 5 discusses establishing such a program.

These electrical safety sections (Clause 4 through Clause 9) provide overall guidance on how to minimize hazardous conditions, how to recognize hazardous conditions when they do exist, and take appropriate measures to avoid human injury from exposure to such conditions.

[14] Information on references can be found in Clause 2.

4.1.1 Definition of *safe*

The term *safe* as used in this document is intended to describe a condition in which electrical safety risks are minimized to an acceptable level. The use of the term *safe* is not intended to suggest or guarantee that absolute electrical safety can be achieved in any situation and/or by compliance the recommended practices set forth herein.

For example, use of terms such as *electrically safe*, *electrically safe work practices*, *safe work condition*, *safe work environment*, *safe design*, *safe distance*, *safe work method*, *safe work area*, *safe use*, etc., describe practices, conditions, etc., in which safety risks are minimized but are not intended to suggest that electrical safety can be or is guaranteed.

4.2 Exposure to electrical hazards

The definition of an electrical hazard indicates that hazards can result from poor physical condition of equipment or facilities, sometimes simply called *unsafe conditions.* It also indicates that injuries can result from the careless or inadvertent actions of people, sometimes simply called *unsafe acts.* Taking precautions to minimize electrical hazards implies that safety considerations regarding such conditions and actions should be given to all aspects of electrical work, including design, installation, commissioning, operating, and maintenance activities.

There are essentially three recognized hazards associated with electricity, as follows:

a) Electrical shock
b) Burns from contact, arcs, or flashes
c) Impact from shrapnel or concussive waves from blasts

These injuries are described in detail in 4.2.1 through 4.2.2.

4.2.1 Electrical shock

Electrical shock hazard is the most common and known form of electrical hazard, and many electrical safety standards have historically been structured to address the shock hazard. Electrical shock affects human beings in the following ways:

a) Electrical current as small as a few milliamperes through the heart can cause disruption of the natural electrical signals that the heart uses to perform its normal functions. Voltage levels as low as 50 V with low skin resistance and electrical current flowing through the chest area can cause fibrillation, which can result in death. This is why all personnel who routinely work on or near energized electrical conductors and circuit parts should be familiar with cardiopulmonary resuscitation (CPR). They may be required to perform CPR on a fellow worker who has experienced an electrical shock.
b) Electrical shock can damage human tissue where the electrical current enters and exits the body. These types of injuries are under the broad category of burn injuries. Within the body, electrical current can also damage internal body parts in its path. The degree of damage is dependent on the amount of the electrical current, the condition of contact points, the duration of exposure to electrical shock, and the path of the electrical current through the body.

c) Electrical shock normally causes the muscles to contract. Due to muscle contraction, the person experiencing the shock may not be able to release the conductor causing the shock. This involuntary grasping may lead to longer exposure to the electrical shock, as the exposed person may not be able to voluntary let go of the hazard.

Several standards offer guidance regarding safe approach distances in order to minimize the possibility of shock from exposed electrical conductors and circuit parts of different voltage levels. One of the most commonly used and referenced standard is NFPA 70E. The limits of approach to exposed energized electrical conductors and circuit parts are discussed in Clause 7 of this standard.

Most electrical personnel are aware that electrical shock may result in electrocution and that by definition electrocution results in death. Just a small quantity of electric energy is required for electrocution. As an example, the current drawn by a 7.5 W, 120 V lamp, passed from hand-to-hand or hand-to-foot, is enough to cause electrocution. It should be emphasized that it is the electrical current, and not voltage, that causes physiological damage to humans.

The results of a sensitivity study from exposure to different values of 60 Hz ac current on a 68 kg (150 lb) human are listed in Table 1. This table provides a ready means of evaluating the physiological effects on a human body. In summary, under the right conditions any current of 6 mA or more may be fatal; those between 90 mA and 4 A can be fatal due to heart disruption. Those above 5 A may be fatal from severe internal or external burns. It is a fact, however, that shocks in this last current range are statistically less likely to be fatal than those in the 90 mA to 4 A range. In view of the diversity of injuries resulting from contact with electrical energy, it is only logical that, to minimize electrical shock or electrocution, exposure to energized conductors and circuit parts should be eliminated where possible, or at the very least minimized as much as possible.

Table 1—Current range and effect on a 68 kg (150 lb) human

Current (60 Hz)	Physiological phenomena	Feeling or lethal incidents
<1.0 mA	None	Imperceptible
1.0 mA	Perception threshold	—
0.5 mA to 2.0 mA	—	Mild sensation.
1.0 mA to 4.0 mA	—	Painful sensation.
6.0 mA to 22 mA	Paralysis threshold of arms	Cannot release hand grip. If no grip, victim may be thrown clear. (May progress to higher current and be fatal.)
18 mA to 30 mA	Respiratory paralysis	Stoppage of breathing (frequently fatal).
90 mA	Fibrillation threshold, 0.5% (greater than or equal to 3 s exposure)	Heart action discoordinated (probably fatal).
250 mA	Fibrillation threshold, 99.5% (greater than or equal to 3 s exposure)	Heart action discoordinated (probably fatal).

Table 1—Current range and effect on a 68 kg (150 lb) human *(continued)*

Current (60 Hz)	Physiological phenomena	Feeling or lethal incidents
4 A	Heart paralysis threshold (no fibrillation)	Heart stops for duration of current passage. For short shocks, heart may restart on interruption of current (usually not fatal from heart dysfunction).
≥5 A	Tissue burning	Not fatal unless vital organs are burned.

Reprinted with permission from: Dalziel, "Effects of electric shock on man," *IRE Transactions on Medical Electronics*, 5:44-62 (1956). See also Dalziel [B8].

As mentioned previously, the effects of shock are dependent upon the amount and path of current that flows through the human body. Typically the magnitude of electrical current established through the human body is a function of the applied voltage and the resistance of the path of the current. Table 2 shows some typical values of skin-contact resistance under various conditions. Table 3 shows typical resistance values of various materials.

Table 2—Human resistance values for various skin-contact conditions

Condition (area to suit)	Resistance (Ω)	
	Dry	Wet
Finger touch	40 000 to 1 000 000	4000 to 15 000
Hand holding wire	15 000 to 50 000	3000 to 6000
Finger-thumb grasp[a]	10 000 to 30 000	2000 to 5000
Hand holding pliers	5000 to 10 000	1000 to 3000
Palm touch	3000 to 8000	1000 to 2000
Hand around 3.8 cm (1.5 in) pipe (or drill handle)	1000 to 3000	500 to 1500
Two hands around 3.8 cm (1.5 in) pipe	500 to 1500	250 to 750
Hand immersed	—	200 to 500
Foot immersed	—	100 to 300
Human body, internal, excluding skin ohms	200 to 1000	

[a] Data interpolated.

Table 3—Resistance values for 130 cm^2 areas of various materials

Material	Resistance (Ω)
Rubber gloves or soles	>20 000 000
Dry concrete above grade	1 000 000 to 5 000 000
Dry concrete on grade	200 000 to 1 000 000
Leather sole, dry, including foot	100 000 to 500 000
Leather sole, damp, including foot	5 000 to 20 000
Wet concrete on grade	1 000 to 5 000

Reprinted with permission from: Lee [B32].

In fibrillation, the victim may not recover consciousness. On the other hand, the victim may be conscious, deny needing help, walk a few feet, and then collapse. Death may occur within a few minutes, or may take hours with vulnerability possible up to a week later. Detection of the fibrillation condition requires medical skill and training. Portable heart defibrillators are often available at the work place or in public buildings, which can be used to stabilize the heartbeat of a victim who has gone into fibrillation. Many of these units provide vocalized step-by-step directions on their use and are suitable for use by non-professionals.

In Figure 1, note the fibrillation line for an exposure time of 5.0 s or more is shown at 75 mA. For shorter times, the threshold current is higher. It should be noted that, if the duration of shock is only 0.004 s, or one-quarter cycle of 60 Hz, the fibrillation threshold current is determined by the energy in the impulse, i.e., Energy = VI(t). Dalziel has determined that the safe limit for impulse shock is 50 Joules (J). For an impulse shock of 4 A at 4 msec from a 120 V source, the impulse shock energy is only 2 J and is unlikely to be harmful to a human. When the impulse shock is 4 A at 4 ms from a 4000 V source, the impulse shock energy is 64 J, so then it is more likely that a harmful injury will occur.

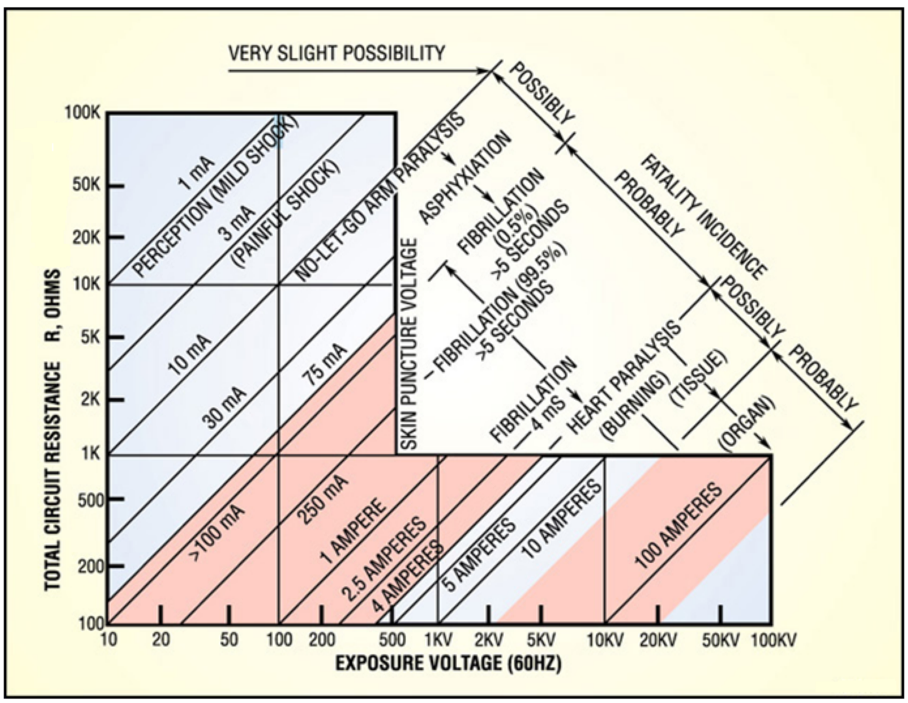


Figure 1—Resistance—voltage—current effect appraisal chart

This sensitivity, increasing with time, explains why a victim who is "frozen" to a current source is much more likely to be electrocuted than one whose contact does not involve hand grasp. A full hand grasp can immobilize the victim such that he cannot let go; hence, the exposure time may extend to many seconds, placing it in range of the 90 mA threshold. In comparison, a casual contact (such as with a fingertip) causes a reflexive retraction of the arm, thereby interrupting the shock current path. In this case, the victim is exposed for only a few thousandths of a second and is much less likely to sustain an injury.

In addition, data has been compiled that shows the corresponding voltage required to force certain current values through a person who has a circuit resistance of 500 Ω. Although this value appears to be rather low for human body resistance, it can be approached by someone who has sweat-soaked cloth gloves on both hands and a full hand grasp of a large energized conductor and a grounded pipe or conduit. Moreover, cuts, abrasions, or blisters on hands can negate the skin resistance, leaving only internal body resistance to oppose current flow. A circuit value as low as 18 V could be dangerous in this instance. For a person with a resistance of 1000 Ω, 90 V could be dangerous; 120 V would be dangerous for a human body with a resistance of 1333 Ω or less.

Defibrillation involves placing electrodes and conductive jelly on the chest. A pulse of over 1000 V dc is applied; this results in current flow up to a few tens of amperes, but only for several milliseconds. These numbers vary with the type of instrument, settings, and other factors. This pulse of dc causes a violent muscle contraction in the chest. Such defibrillation places the heart in asystole: a complete stoppage of electrical activity of the heart. Within a few seconds, the heart will usually resume a normal pattern of beating.

Once the heart goes into ventricular fibrillation it usually does not spontaneously revert to a normal heart rhythm, though it may do so.

4.2.2 Burns from contact, arcs, or flashes

Electrical shock can be a hazard to life. Many people, however, have experienced minor shocks with no dire consequences—not even skin burns. This tends to make people somewhat complacent around electricity. What most people do not know is that approximately half of the serious electrical injuries involve burns. Electrical burns include not only burns from contact, but also radiation burns from the extreme temperatures of electric arcs that result from short circuits due to poor electrical contact or insulation failure. The electric arc between metals is, next to the laser, the hottest thing on earth. It is about four times as hot as the sun's surface, or 20 000 °K (35 000 °F). Where high arc currents are involved, burns from such arcs can be fatal, even when the victim is some distance from the arc. Serious or fatal burns can occur at distances of more than 304 cm (10 ft) from the source of a flash. In addition to burns from the flash itself, clothing is often ignited. Fatal burns can result because the clothing cannot be removed or extinguished quickly enough to prevent serious burns over much of the body. Wearing clothing made of meltable fibers will also add to the problem. Because of this Occupational Safety and Health Administration (OSHA) 29CFR1910.269(l)(6)(iii) requires the employer to have employees who are exposed to flames or electric arcs wear only clothing that will not increase the extent of injury. Clothing that is made of acetate, nylon, polyester, or rayon is prohibited unless the employer can demonstrate that the fabric has been treated to withstand the conditions that may be encountered.

Visible skin burns from direct contact electrical shock are caused by the I^2R heating of body tissue and vary according to many factors such as voltage, contact resistance, skin conditions, contact duration, and bodily current path. It has been estimated by various researchers that the minimum current necessary to produce first-degree skin burns is an exposure of approximately 100 mA for 1.0 s to 9.0 s for a skin area of 1.0 cm^2.

Even at what a person may believe to be a large and safe distance, serious or fatal injuries can occur to a person's bare skin or skin covered with flammable clothing as a result of a high energy electric arc. Electrical workers are frequently in the vicinity of energized electrical conductors or circuit parts. It is only the relative infrequency of such arcs that has limited the number of injuries. Examples of exposure are

working on open panelboards, switchboards, or motor control centers, racking in or out circuit breakers or contactors, hook-stick operation of medium-voltage fuses, testing of cable terminals, grounding before testing, or working in manholes near energized cables.

Several studies, tests, and technical papers have been written on the subject of electrical shock and arc-flash hazards (see Annex A). Safety standards and procedure requirements are continuing to be developed to recognize the fact that arcs can cause serious injuries at significant distances from energized sources. Equally important in these new safety standards is the fact that only trained and qualified people with shock and arc-rated protective equipment are permitted to approach energized electrical conductors or circuit parts. Spectators, or unqualified persons, should stay away because, even though they think they are far enough away, they generally do not have an understanding of what is a safe approach distance. The *arc-flash protection boundary* (defined as when an arc flash exists, an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur) can be calculated using the equations given in IEEE Std 1584 or guidance can be found in NFPA 70E. Depending upon the fault energy available, spectators can be seriously injured or killed at great distances from the initiation point of an arc.

4.2.3 Nature of arcs

Electrical arcing is the term that is applied to the passage of substantial electrical currents through what had previously been air. It is initiated by flashover or the introduction of some conductive material. Current passage is through ionized air and the vapor of the arc terminal material, which is usually a conductive metal or carbon. In contrast to current flow through low-pressure gases such as neon, arcing involves high temperatures of up to, or beyond, 20 000 °K (35 000 °F) at the arc terminals. No materials on earth can withstand these temperatures; all materials are not only melted, but vaporized. The vapor of the terminal material has substantially higher resistance than solid metal, to the extent that the voltage drop in the arc ranges from 29.53 V/cm (75 V/in) to 39.37 V/cm (100 V/in), which is several thousand times the voltage drop in a solid conductor. Since the inductance of the arc path is not appreciably different from that of a solid conductor of the same length, the arc current path is substantially resistive in nature, thus yielding unity power factor. Voltage drop in a faulted large solid or stranded conductor is about 0.016 V/cm to 0.033 V/cm (0.042 V/in to 0.083 V/in).

For low-voltage circuits, an arc length of 29.53 V/cm to 39.37 V/cm (75 V/in to 100 V/in) consumes a substantial portion of the available voltage, leaving only the difference between source voltage and arc voltage to force the fault current through the total system impedance, including that of the arc. This is the reason for the "stabilization" of arc current on 480Y/277V circuits when the arc length is of the order of 10.16 cm (4 in), such as with bus spacing.

For higher voltages, the arc lengths can be substantially greater, e.g., 2.54 cm (1 in) per 100 V of supply, before the system impedance starts to regulate or limit the fault current. Note that the arc voltage drop and the source voltage drop add in quadrature, the former resistive, the latter substantially reactive. The length or size of arcs in the higher voltage systems thus can be greater and can readily bridge the gap from energized parts to ground or other polarities with little drop in fault current.

The hazard of the arc is not only due to the level of voltage. Under some cases it is possible to generate a higher energy arc from a lower voltage than from a higher voltage. The amount of arc energy generated is dependent upon the amount of short-circuit current available and the amount of time before the fault causing the arc is cleared (removed from the power source) by a circuit breaker or fuse. This highlights the need for workers to be cognizant of the arc hazards not only on higher voltages, but on 600 V rated equipment as well.

4.2.4 Arc as a heat source

The electric arc is widely recognized as a very high-level source of heat. Common uses are arc welding of metals, electric arc furnaces to produce molten steel, and even electric cauterizing of wounds to seal against infection while deeper parts are healing. The temperatures at the metal terminals are extraordinarily high, being reliably reported at 20 000 °K (about 35 000 °F) and special types of arcs can reach 50 000 °K (about 90 000 °F). The only higher temperature source known on earth is the laser, which can produce 100 000 °K (about 180 000 °F).

4.2.5 Development of arc size

In a bolted fault there is no arc, so in this instance comparatively little heat will be generated. Should there be appreciable resistance at the fault point, temperatures could rise to the melting and boiling points of the metal, and an arc could be started. The longer the arc becomes, the more of the available system voltage it consumes. Consequently, less voltage is available to overcome the supply impedance, and the total current decreases.

4.2.6 Effect of temperature and incident energy on human tissue and clothing

The human body can exist in only a relatively narrow temperature range that is close to normal blood temperature, which is around 36.5 °C (97.7 °F). Survival much below this level requires insulation with clothing. Temperatures that are slightly above this level can be compensated for by perspiration. Studies show that at skin temperature as low as 44 °C (110 °F), the body temperature equilibrium mechanism begins to break down in about 6 h, and cell damage can occur beyond 6 h at that temperature. Between 44 °C (110 °F) and 51 °C (124 °F), the rate of cell destruction doubles for each 1.0 °C (1.8 °F) temperature rise. Above 51 °C (124 °F), the rate of cell destruction is extremely rapid. At 70 °C (158 °F), only a one second duration of exposure is sufficient to cause total cell destruction.

NFPA 70E-2009 defines incident energy as “the amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event. One of the units used to measure incident energy is calories per centimeter squared (cal/cm^2).” It is estimated that for systems of 600 V or less, a 4 ft arc-flash protection boundary should be established based on the product of a clearing time of 2.0 cycles (0.033 s) and an available bolted fault current of 50 kA or any combination that does not exceed 100 kA cycles.

Where the voltage is greater than 600 V the arc-flash protection boundary shall be the distance at which the incident energy equals 5.0 J/cm^2 (1.2 cal/cm^2). For situations where fault-clearing time is equal to or less than 0.1 s, the arc-flash protection boundary shall be the distance at which the incident energy level equals 6.24 J/cm^2 (1.5 cal/cm^2)

Arc-flash protection boundary is defined as “when an arc flash exists, an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur.”

4.2.7 Impact from blasts

The rapid expansion of air caused by a fault current has been recognized for some time as one of the electrical hazards. What was not recognized previously was the fact that this blast and its effects could be calculated, and precautions against its effects could be taken.

As in shock and arc damage, the first hazard mitigation technique to employ to avoid the blast hazard is to stay away from energized conductors and circuit parts. Unfortunately, electrical work is a profession that

sometimes requires exposure to this hazard. The total exposure can be reduced, however, by not using electrical rooms for offices, warehouses, or break rooms. Sometimes electrical equipment must be maintained and operated while it is energized. The risk of a fault occurring while people are in close proximity to this equipment shall be taken into account.

4.2.8 Pressures developed by arc blasts

People are exposed to two dangers from electrical arcs: burns and blasts. The blast can cause falls and other injuries, as well as damage nearby structures. A relationship is developed between arc current and pressure for an applicable range of distance.

For familiarization with some units used for pressures in the SI (metric) system, the following may be useful:

— 1 newton (N) = 0.2248 lb force (lbf)

— 1 newton/m^2 = 0.0209 lb/ft^2

— 1 atmosphere (atm) = 14.7 psi = 2 116 lb/ft^2 = 1.0125 × 10^5 N/m^2

4.2.9 Arc forces defined

Reports of the consequences of electrical power arcs in air include descriptions of the rearward propulsion of personnel who were close to the arc. In many cases, the affected people do not remember being propelled away from the arc, often failing to remember the arc occurrence itself. The relative infrequency of power arcs has tended to distract interest from determining the nature and magnitude of this pressure.

Also, the heat and molten metal droplet emanation from the arc can cause serious burns to nearby personnel, a fact that has also tended to reduce interest in the rearward propulsion and pressures generated.

Another consequence of arcs is structural damage. One power arc in a substation of the Quebec Hydroelectric System caused collapse of a nearby substation wall. To determine the magnitude of pressure that is generated by the arcing fault, M. G. Drouet and F. Nadeau of the Institut de Recherche de l'Hydro-Québec were assigned to develop theoretical and practical bases for this phenomenon. The results of their work are described in a 1979 paper (see Drouet and Nadeau [B14]).

Drouet and Nadeau's work shows that actual pressures are an order of magnitude greater than theoretical values. According to a reviewer, Dr. Nettleson, this phenomenon is attributed to a very high frequency component of pressure that is not recorded by measuring apparatus. Regardless of this, the measured amplitudes of pressures from a 100 kA, 10 kV arc reached about 2 × 10^4 N/m^2 (400 lb/ft^2) at a distance of 1 m (3.3 ft). This pressure is about ten times the value of wind resistance that walls are normally built to withstand, so such an arc could readily destroy a conventional wall at distances of about 12 m (40 ft) or less. A 25 kA arc could similarly destroy a wall at a distance of 3 m (9.5 ft).

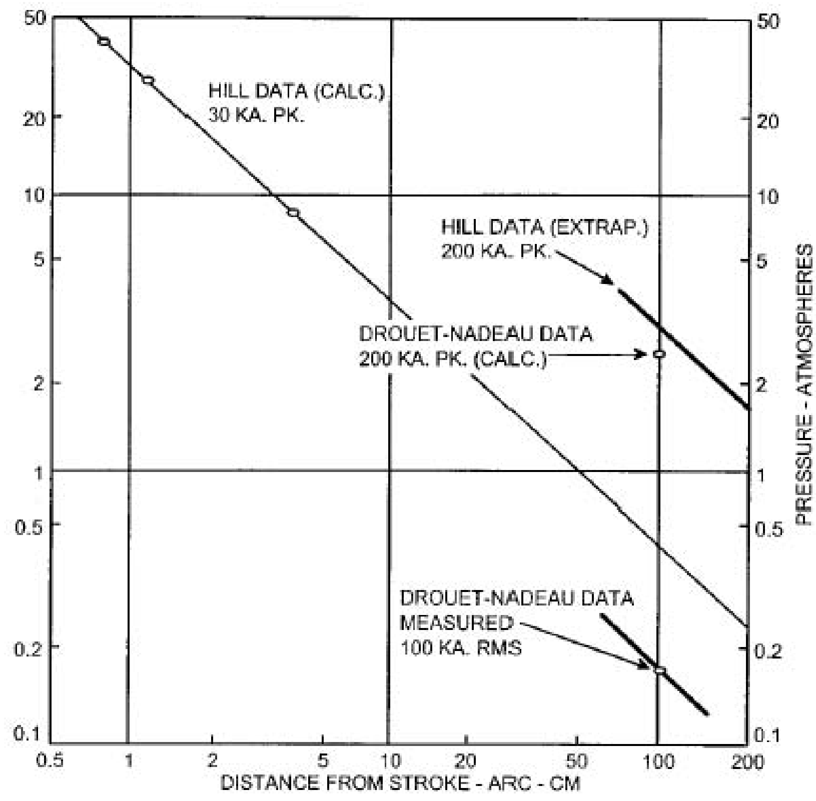
Pressures on projected areas of individuals at 0.6 m (2 ft) from a 25 kA arc would be about 7 750 N/m^2 (160 lb/ft^2). This is sufficient to place a force on the front of a person's body of about 2100 N (480 lbf). Such pressures are also found to be damaging to human ears. Mandatory hearing protection, as in other high noise-level locations, should be considered during the hazard analysis (see 7.3.5 and 7.3.6.).

Additional research as to the effects of electric arcs and their resultant acoustic forces is being performed under a collaborative effort between the IEEE and NFPA; they have formed the Arc Flash Collaborative Research and Testing Project. In 2006 the fund-raising for this project was initiated. The principle purpose of this joint research and testing initiative is to provide information to update both IEEE Std 1584 and NFPA 70E. It is expected that much new information will be brought forth as the research progresses.

4.2.10 Development of arc pressure

The pressures from an arc are developed from two sources: the expansion of the metal when boiling and the heating of the air by passage of the arc through it. Copper expands by a factor of 67 000 in vaporizing, similar to the way that water expands about 1670 times when it becomes steam. This accounts for the expulsion of near-vaporized droplets of molten metal from an arc. These are propelled for distances of up to about 3 m (10 ft). It also generates plasma (ionized vapor) outward from the arc for distances proportional to the arc energy. With copper, 53 kW/s vaporizes 0.328 cm^3 (0.05 in^3), thereby producing 54 907 cm^3 (3 350 in^3) of vapor. Therefore, 16.39 cm^3 (1 in^3) of copper vaporizes into 1.098 m^3 (38.8 ft^3) of vapor.

The air in the arc stream expands in warming up from its ambient temperature to that of the arc, or about 20 000 °K (35 000 °F). This heating of the air is related to the generation of thunder by the passage of lightning current through it. Dr. R. D. Hill developed theoretical pressures at distances of 0.75 cm to 4 cm (0.295 in to 1.575 in) from a 30 kA peak lightning strike. These pressures ranged from 40 atm down to 9 atm. Dr. Hill's data are plotted in Figure 2, on log-log scale, and the straight-line of these points is extrapolated to 100 cm (39.37 in) distance, at which distance the pressure would have been 0.45 atm. Multiply this 0.45 by 200/30, to match the peak power of the Drouet-Nadeau (D-N) tests, and the Hill data becomes 3.3 atm, rather close to the D-N theoretical value of 2.7 atm.

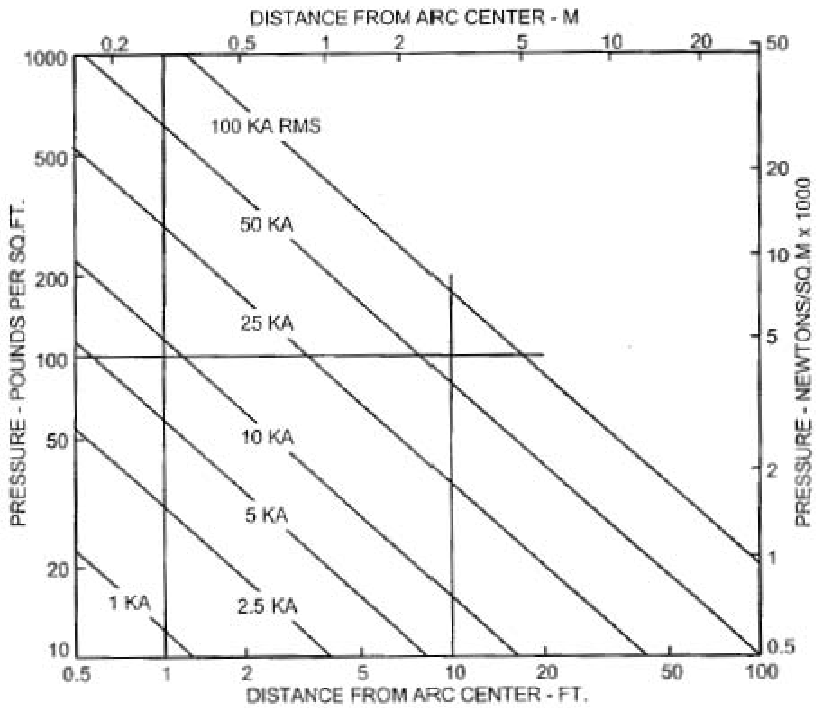


Reprinted with permission from: Lee [B32].

Figure 2—Pressure vs. distance from stroke or arc

The actual measured pressure by D-N from a 200 kA peak, 100 kA rms current was 0.19 atm or 0.07 times the calculated theoretical pressure. Since this is the only available measured pressure level, it is used to generate a family of lines, shown as Figure 3. In this figure, pressures are shown for arc currents from 1 kA to 100 kA rms, for a range of distances of 15 cm to 30 m (0.5 ft to 100 ft), from the arc center to the point

of interest. From this, the pressure may be determined for a 25 kA arc at a distance of 60 cm (2 ft) to be 7 656 N/m^2 (160 lb/ft^2). This pressure can produce significant physical trauma, however it can propel personnel close to an arc rapidly away from the heat source, which can substantially reduce the degree to which they are subjected to burns.



Reprinted with permission from: Lee [B32].

Figure 3—Pressure vs. distance from arc center

The hot vapor from the arc starts to cool immediately. While hot, however, it combines with the oxygen of the air, thus becoming the oxide of the arc metal vaporized content. These continue to cool, solidify, and become minute particles in the air, appearing as black smoke for copper and iron, and gray smoke for aluminum. These particles are still quite hot, and cling to any surface they come in contact with, actually melting into many insulating surfaces they may contact. Many people think that these are carbon particles. Once attached to a surface, the oxide particles are very difficult to remove and surface rubbing is not effective. For example, to remove metal oxide particles attached to a plastic insulation surface, abrasive cleaning followed by a new surface varnish are typically required. Otherwise the metal oxide particles deposited on the insulation surface could increase the surface leakage current magnitude and cause insulation failure within days.

Persons exposed to severe pressure from proximity to an electric arc flash are likely to suffer short-time loss of memory and may not remember the intense explosion of the arc itself. This is a brief concussion that interferes with the transfer from short-time memory to long-time memory. This phenomenon has been found true even for high-level electrical shocks.

It is evident that persons working in conditions where power arcing is possible should be protected not only against arc burns, but also against arc pressure, from such things as falling and ear damage or other hazards.

4.3 Case histories

As the following incidents show, a variety of things can go wrong when working on or near electrical conductors and circuit parts, even when they are thought to be de-energized. These incidents demonstrate how important it is to strictly control such work by using only trained and qualified personnel who know and use safe practices and appropriate protective equipment. The incidents in 4.3.2 prove that the use of proper protective equipment does save lives and protect employees from injury.

4.3.1 Incidents resulting in injury

4.3.1.1 Case no. 1—shock

A mechanic, while working on some equipment in the rear of a power-type circuit breaker auxiliary metering compartment, accidentally came in contact with adjacent energized transformer terminals. He apparently had not checked for other energized components in the vicinity in which he was working. He required medical treatment for shock.

4.3.1.2 Case no. 2—shock

A construction electrician was assigned to a job installing wiring for lighting fixtures in a 208Y/120V system. The job was already partially completed. The electrician was told by the foreman that everything was “dead.” The “home run” was already installed, and those wires were protruding from a junction box. The electrician was on a ladder and began to remove the insulation from the home-run wires using “wire skinners” with one hand. His other hand was holding the wires, but was also in contact with the box. He was not wearing gloves, and received a severe shock causing him to fall from the ladder. Fortunately, he received only minor bruises from the fall. He later said, “I should have checked myself to see that it was really dead.”

4.3.1.3 Case no. 3—severe shock

A field engineer was using portable radiography equipment to inspect the quality of medium-voltage cable terminations. A construction electrician was assisting him. The radiography equipment consisted of a cathode ray tube in a metallic casing (called an *X-ray head*) and a control unit. A control cable interconnected these units. The engineer was on top of a stepladder, leaning against the switchgear enclosure, grasping the handles of the X-ray head, and adjusting its position. The electrician proceeded to plug the control unit into a 120 V outlet and connect the control cable. Suddenly, the engineer received a severe shock and fell off of the ladder. It was later determined that the plug-in connection between the control cable and the control unit was incorrectly polarized. The electrician had forced the connection together in the wrong orientation, putting 120 V on the casing of the X-ray head. The engineer was taken to the medical department at the site and was observed for the remainder of the day. He said his grasp was locked onto the handles momentarily until his weight broke him loose during his fall. He complained of muscular problems for several days afterward.

4.3.1.4 Case no. 4—shock and burn

An electrician was part of a crew that was operating a 15 kV switch in a new electric power system. One switch blade did not close properly. As other crew members packed up their tools and prepared to return to the shop to discuss the problem with supervision, they heard a noise. They turned around to see the switch door open, and the electrician surrounded by smoke and flames. While trying to read a part number, the electrician had accidentally made contact with an energized part of the switch, and a flash had occurred. A

coworker pulled the man from the switch and revived him using CPR. Nine months later, after having some fingers and toes amputated, the electrician was still receiving medical treatment as a result of the accident.

4.3.1.5 Case no. 5—shock and burn

A construction electrician had been running wiring all day long for several new heating and air conditioning units in the space above a suspended ceiling. The electrical feeder that supplied the new installation was a 480Y/277V system, but it had been verified as de-energized earlier in the day; however, no lockout had been installed. The electrician, at one point late in the day, began to prepare the main feeder for connection. He was working on a ladder and started to remove the insulation from one of the wires. He did not have gloves on. He let out a yell as he became "hung up" on the wires. Apparently, sometime during the day, someone had turned on the feeder breaker. A carpenter, working right beside the electrician, recognized that the electrician was "frozen" to the wires due to muscle contraction. The carpenter used a piece of lumber to knock the electrician off the ladder, breaking him free of the wire. The electrician fell onto the floor, rolled, and banged against a wall. He was taken to the hospital and kept for two days for treatment and observation, having received a severe shock, second degree burns to both hands, and facial cuts from the fall.

4.3.1.6 Case no. 6—flash, blast, and burns

A contract electrician had finished drying out a 480 V bus duct. While working on a ladder, reinserting the plug-in units onto the bus, he encountered difficulty getting one of the units to make up properly. He banged on the plug-in unit and was met with a flash and blast that severely burned him and knocked him off the ladder. He was not wearing any protective clothing.

4.3.1.7 Case no. 7—fatal shock

An electrician was installing a 277 V lighting fixture in an industrial plant. Turning the power off was inconvenient, as it involved winding his way around and through some vessels and pipes, and going up two flights of stairs to the lighting panel. Apparently thinking that there was not much danger in this "minor" job, he did not bother to turn the power off. Working in an existing junction box, he made up two of the connections and was trying to remove an existing wire nut to install the third wire. He was having difficulty removing the nut, so he used a lug crimping tool to try to pull and twist the wire nut off. He gripped the tool too hard and it cut through the outer shell of the wire nut, making contact with the energized wire inside. He was electrocuted.

4.3.1.8 Case no. 8—fatal shock and blast

A contract electrical maintenance crew had arrived the night before a planned shutdown of some low- and medium-voltage equipment. The plant engineer offered to show the foreman the equipment on which they would be working the next day. He opened the doors to the medium-voltage equipment, leaving the doors open as he went down the line. Two members of the crew trailed the plant engineer and the foreman, and were intrigued with some discoloration on a cable terminal wrapping in the first cubicle. One electrician, not recognizing that the cubicle was bottom fed, assumed that the cable was de-energized, and approached it too closely, possibly even touching it. He was electrocuted and, at the same time, initiated a blast that severely impacted the second electrician. When questioned on the event, the second electrician was unable to remember what happened.

4.3.1.9 Case no. 9—burns

Power switchboard operators and a shift foreman were racking in a 2.4 kV circuit breaker. As they were trying to raise the breaker into position with the dc elevator motor, they experienced trouble and burned up the elevator motor in the process. The shift foreman, who had limited experience with this particular switchgear, called to get some assistance racking in the circuit breaker. Another foreman and operator arrived. Since trouble had been experienced racking the breakers in and out before, the operators thought that possibly the breaker was either rusty from lack of regular operation or affected by climate problems. They decided to continue racking the breaker in manually. As the breaker approached approximately 5 cm (2 in) of being fully racked in, a flash from the cubicle occurred. Fortunately, the operator racking in the breaker had a full arc-rated flash suit on, and his burns were minimized. The foreman who was a distance from the cubicle, but had no arc-rated flash suit on when it faulted, received a slight burn on one arm and his face as he moved to help the operator. The incident would have likely been a fatality if the operator had not worn an arc-rated flash suit. The switchgear behind the operator had the nameplate burned off. The foreman who was some distance from the incident and was wearing protective clothing was injured more than the operator in the arc-rated flash suit.

4.3.1.10 Case no. 10—burns

An electrical worker was assigned the task of upgrading the controls on a 480 V, 400 A automatic transfer switch. There were a total of seven switches to be modified, and on the last one the task involved adding switch position contacts to indicate whether the unit was in normal or emergency position. The controls were isolated from the power source and the components added, however the facility had added a non-factory micro-switch contact on a piece of balsa wood. While in the process of removing the non-factory No. 14 control wiring, the wire slipped and contacted the 480 V bus of the transfer switch, causing an arc flash and resultant burns to the unprotected skin. He was not wearing arc-rating protective clothing while in the transfer switch enclosure. See Figure 4.

Figure 4—Electrical burns

4.3.1.11 Case no. 11—burns

Three people were burned when the 2.4 kV motor contactor they were racking in tried to close when the main power stabs made contact with the bus. The unit was set to an auto-start position and as soon as the control power transformer became energized, the contactor picked up, causing arcing at the stabs. The

resultant ionized gas then caused a phase-to-phase fault. The workers were not wearing arc-rated flash suits.

4.3.1.12 Case no. 12—burns

A set of dc switches was not operated in the proper sequence. This resulted in a direct short when one of the switches was closed. An arc occurred across the switch as the operator was closing it. The operator received burns to his neck and arms, even though he was wearing required arc-flash protection. The injury was due in part to the way that the operator had put on his flash suit. He did not properly close the hood and jacket, which allowed hot gases to enter the protective barrier, injuring the worker.

4.3.1.13 Case no. 13—fatal burns

An electrician was spray-washing a 480 V switch with a solvent. The garden sprayer nozzle made contact across the open switch. There was a large amount of fault current available at this point in the circuit. The electrician was fatally burned from the resultant arc flash. A wooden handrail that was 3.05 m (10 ft) from the switch ignited from the extreme temperatures.

4.3.1.14 Case no. 14—burns and blast

A shopping center was being enlarged and new switch units were being added to a 480 V substation power center. A new vertical bus was added to an existing vertical section to accommodate new switch units. The bolts attaching the vertical bus to the riser from the main horizontal bus were installed so that the threaded ends were toward the back of the switch unit. The bolts were approximately 2.54 cm (1.0 in) longer than required to secure the bus to the riser. The net result was the bolt ends were only about 0.16 cm (1/16 in) from the new switch enclosure. An electrician and a helper were inserting a 400 A, 600 V fuse in a newly-installed fusible switch. Pressing the fuse into the fuse mounting, the box was deflected into the switchgear and made contact with the energized bolt ends. This initiated a power fault of approximately 100 kA rms. The electrician was seriously burned by the infrared radiation from the arc, and his clothes were ignited by the molten copper droplets expelled from the arc. He was propelled backwards by approximately 2 670 N (600 lb/ft) of pressure on his chest from the fault, striking the front of another section of switchgear that was 2.74 m (9 ft) from the unit he had been working on. The helper, who had been watching him at the open door of the switch enclosure, was propelled backward approximately 7.5 m (25 ft), completing two backward somersaults before ending up against a wall. He was not injured, and hurried back to the electrician, helping him up and extinguishing the flames of his clothes. A calculation indicated that the electrician had been propelled backwards nearly 0.6 m (2 ft) in 0.1 s, which substantially reduced the radiation burning.

4.3.1.15 Case no. 15—blast and flash burn

Electricians were installing new wiring in an older plant. One horizontal plug-in bus duct was to be fed through an existing empty conduit from an existing air-break switch. The conduit from the switch to the bus duct was attached to the top of the switch enclosure, and the line terminals of the switch were energized. The electricians were passing a fish tape from the bus duct end toward the switch, but they could not push it the entire distance. One of the electricians then took another fish tape and started to push it up from inside the switch to hook it onto the hook end of the first fish tape. He did not de-energize the line terminals of the switch or put any insulation guarding material over the energized terminals. While pushing on the second fish tape it buckled toward, and touched, the energized terminal initiating a phase-to-ground fault arc from an energized switch terminal to the fish tape, which was grounded to the inside of the conduit. The electrician was knocked backwards and extensively burned.

4.3.1.16 Case no. 16—blast

Two workers in a plant were walking away from a recently closed 480 V switch when it exploded with a heavy arc. Approximately 2.4 m (8.0 ft) away from the faulted switch one worker received substantial arc droplet spot melting on his nylon jacket. Both workers had their hearing adversely affected. One continued to experience pain and required medical care for over fourteen months after the incident.

4.3.1.17 Case no. 17—blast

In an area of the country known for large amounts of snowfall, a number of outdoor substations had been experiencing 480 V bus faults, particularly when springtime came. Investigation showed severe water entry onto the interior components due to the condensation of warmer air against the underside of the still-cold top of the switchgear. The substation cubicle heaters were not operative due to a previous failure of the devices. At the point at which the water droplets struck bus, breaker insulation tracking was initiated, which in turn created arcing. One of the faults occurred when a plant electrician was standing approximately 0.9 m (3 ft) from the front of the 480 V switchgear. The arc fault was on the buses behind the breaker fronts. Pressure through the opening below the bottom breakers, however, propelled the electrician back against the substation fence, approximately 2.1 m (7.0 ft) from the switchgear. Fortunately, he was not seriously injured.

4.3.1.18 Case no. 18—electrocution

A fast-food restaurant worker was kneeling on the floor to insert the male plug of a portable electric toaster into a 120 V, 20 A receptacle that was mounted in a grounded metal enclosure with a hinged cover. The floor was wet because it had been recently mopped. As the worker held the cover open with his left hand and began to insert the male plug into the receptacle outlet, his index finger apparently touched the energized prong of the plug. The victim was found convulsing, and he died shortly afterwards.

4.3.1.19 Case no. 19—double electrocution

Two painters were using an aluminum extension ladder to paint a metal light pole. One worker was standing on the ladder painting, and his coworker was on the ground holding the ladder. The ladder slipped away from the pole and contacted a 12 460 V overhead power line that was very near the pole. Both painters were electrocuted.

4.3.1.20 Case no. 20—double electrocution and burns

Three workers were using a telescoping boom crane to move a section of steel framing at a construction site. As the section of framing was being moved, it came in contact with a 23 000 V overhead power line. Two of the three workers who were in direct contact with the load were electrocuted, while the third received serious electrical burns.

4.3.2 Incidents where protection prevented injury

4.3.2.1 Case no. 21—flash, no injury

An operator was in the process of closing a disconnect switch on a 480 V, Size 4, NEMA 1 starter when it faulted and initiated an arc-flash event. The operator, who was wearing the required arc-flash protection, had stood to one side and had turned away while operating the switchgear. The operator was not injured,

but his protective gloves were scorched by molten copper. The switchgear door was blown open, and the door and switchgear on the opposite side of the aisle were burned.

4.3.2.2 Case no. 22—flash and blast, no injury

An operator was sent out to clear and tag out "Pump A" for maintenance. He shut Pump A down, blocked the valves, and then went to the motor control center to open and tag the disconnect switch. He mistakenly opened the switch to "Pump B," which was running and loaded. Arcing within the switch caused an arc flash and blast, thus blowing the switch compartment door open. Fortunately, the operator was wearing an arc-rated flash suit and was not hurt.

4.3.2.3 Case no. 23—flash and blast, no injury

A fuse mechanism on a 2 300 V non-load-break fused disconnect caused a phase-to-phase fault when closed in with an insulated hot stick. The employee was wearing an arc-rated flash suit. The hood face shield and jacket had molten copper spots. No injury resulted from the fault.

4.3.2.4 Case no. 24—flash, no injury

An operator attempted to close a pole-mounted no-load disconnect switch feeding a 15 kV oil circuit breaker, with the circuit breaker in the closed position. The breaker had been left in the closed position following the testing of a primary bushing that had been replaced. An operator and a supervisor had visually inspected the breaker before operating the disconnect switch and thought the breaker was open. The breaker position indicators were over-sprayed with paint, and the breaker was mistakenly assumed to be open when it was closed. The operator put on an arc-rated flash suit with rubber gloves and proceeded to close the disconnect switch. He was standing under the 15 kV disconnect using the gang operator to close the disconnect switch. As the disconnect switch was closed, an electrical arc occurred. The resultant fault broke the insulator, and molten copper and broken porcelain particles flew toward the operator. A protective relay system cleared the fault current. No injury occurred as a result of this incident.

4.3.2.5 Case no. 25—flash and blast, no injury

An operator was in the process of energizing a motor from a push-button start switch on a 480 V switchgear lineup. When he initiated the start switch, which was located on the door of the motor-starter unit, the switchgear faulted and blew up. He was wearing arc-rated protective equipment and was not hurt. He immediately put out the resulting fire. The switchgear and its associated light and wiring were checked for faults. No conclusive evidence as to the cause of the fault was found, but coincidentally sandblasting work had been performed earlier within the immediate area of the switchgear.

4.4 Reasons for practicing electrical safety

There are at least three good reasons for practicing electrical safety, as follows:

a) Personal considerations, which affect everyone as caring individuals and employers
b) Business considerations, because safety makes good business sense
c) Regulatory and legal consideration, because violations can result in fines and/or imprisonment

4.4.1 Personal considerations

The first reason for practicing electrical safety is due to the adverse way in which we are personally affected by electrical incidents, especially since we know that they are often avoidable. Even if we do not get hurt ourselves, it may still deeply affect us and hurt us emotionally if a family member, an acquaintance, or a fellow employee is injured or killed. It even stirs up feelings of sympathy in us when we hear about a serious electrical injury or fatality that happened to a stranger. For these reasons, we should exercise safe work practices, look out for the safety of those around us, and help educate as many people as we can about electrical safety and the ensuing hazards associated with electrical energy.

4.4.2 Business considerations

Safety at the workplace is closely tied to a business outcome. The "bottom line" of most businesses is to keep costs down and earn profits. If serious electrical injury, death, or property damage occurs at a particular company facility as a result of unsafe acts or unsafe conditions, an incident of this sort normally results in substantial damage to a company's tangible and intangible assets. Consider the possible costs of the following items:

a) Time lost by the injured employee
b) Medical bills
c) Time lost by supervisors and managers trying to find out what really happened
d) Time lost and aggravation caused by answering many questions from all directions
e) Time lost by supervisors and managers writing reports
f) Time lost by other employees sympathizing and discussing the accident
g) Lost production quantity or quality
h) Loss of test and research data if unexpected electrical outages result
i) Possible increase in insurance rates
j) Possibility of lawsuits by the injured, or the family, claiming negligence
k) Possible intervention and fines by a law enforcing agency such as OSHA
l) Payment for any necessary outside consultants
m) Time lost escorting investigators
n) Discomfort of explaining "why" to the family of the victim
o) Lowered morale of fellow employees if employer is thought to be negligent
p) Replacement or repair costs of damaged equipment
q) General disruption of the normal operating routine
r) Mistrust by customers of a company with a poor safety record

Some of the preceding costs are difficult to put a value on, but they are real. The cost of one serious incident could be more than the cost of establishing and maintaining a good electrical safety program for several years. In the long run, the safe way is the least expensive way to run a business.

4.4.3 Regulatory requirements and legal considerations

The third and most compelling reason for practicing electrical safety is the fact that regulatory bodies and jurisdictions having authority mandate certain safety requirements such as electrical safety and fire protection. Breaking these laws could mean fines for companies and possibly even imprisonment for management personnel.

In the U.S., there are four main standards relating to electrical safety for use by governing agencies, as follows:

a) Occupational Safety and Health Administration (OSHA) standards
b) National Electrical Code® (NEC®) (NFPA 70®)
c) Standard for Electrical Safety in the Workplace (NFPA 70E®)
d) National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2)

There are also other recognized standards and guides that contain electrical safety information that might be referenced in a legal case.

4.4.3.1 OSHA regulations

The U.S. Department of Labor has written laws under Title 29 of the Code of Federal Regulations (29CFR) that establish requirements for electrical installations and electrical safe practices in that country. These are commonly called the *OSHA Regulations*. Part number 1910 covers the requirements for general industry, and Part number 1926 covers the requirements for the construction industry.

NOTE—Throughout the rest of this guide, OSHA regulation numbers will be referred to by abbreviation. For example, definitions for the electrical subpart are contained in 29CFR1910.399.[15]

The subparts of Part 1910 that are of particular interest relative to electrical safety are as follows:

— Subpart S—Electrical, all sections
— Subpart R—Special Industries, Section 1910.269—Electric Power Generation, Transmission, and Distribution
— Subpart I—Personal Protective Equipment, Section 1910.137—Electrical Protective Devices
— Subpart J—General Environmental Controls, Section 1910.147—Hazardous Energy Control (Lockout/Tagout)

The Subparts of Part 1926 that are of particular interest relative to electrical safety are as follows:

— Subpart K—Electrical, all sections
— Subpart V—Power Transmission and Distribution, all sections

There are many other subparts in both 29CFR1910 and 29CFR1926 that refer to topics that are not directly electrical safety in nature, but which are applicable to electrical work. It would be wise to review the OSHA Table of Contents of these two parts.

Although it is not an easy task to fully educate everyone with necessary safety measures, all employees are required to abide by these laws, and any electrical safety program in the U.S. shall be based on these laws.

[15] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

Other countries of the world may have their own laws on which their electrical safety programs should be based. In any case, before commencing electrical work, the utmost care must be taken to fully understand and follow the applicable laws regarding electrical safety.

4.4.3.2 National Electrical Code

NFPA 70-2011, commonly called the NEC, is well known as an electrical fire protection and safety document related to the installation of "premises" wiring. As defined in the NEC, premises wiring is "interior and exterior wiring, including power, lighting, control, and signal circuit wiring together with all their associated hardware, fittings, and wiring devices, both permanently and temporarily installed. This includes (a) wiring from the service point or power source to the outlets or (b) wiring from and including the power source to the outlets where there is no service point. Such wiring does not include wiring internal to appliances, luminaires, motors, controllers, motor control centers, and similar equipment." In itself, the NEC is a standard of advisory information offered for use in law and for regulatory purposes. It can be, and is, adopted and made mandatory by many governing agencies in the U.S. and other countries, thereby giving it the force of law in those jurisdictions. It should also be remembered, however, that the NEC is a minimal standard; therefore, its requirements sometimes have to be exceeded to meet functional necessities, good engineering judgment, and enhanced safety practices. The NEC will be referenced many times in this guide.

4.4.3.3 National Electrical Safety Code

The NESC applies primarily to outdoor electrical transmission, distribution, and communication systems, equipment, and associated work practices; as opposed to the NEC, which concerns itself primarily with premises wiring. The NESC contains the following:

a) Introduction, definitions of special terms, references, and grounding methods for electric supply and communication facilities
b) Rules for installation and maintenance of electric supply stations and equipment
c) Safety rules for installation and maintenance of overhead electric supply and communication lines
d) Safety rules for installation and maintenance of underground electric supply and communication lines
e) Rules for the operation of electric supply and communication lines and equipment

4.4.3.4 Other standards

Another electrical safety standard published by the NFPA is NFPA 70E. When the OSHA electrical standards were first published as a Final Rule on January 16, 1981, they were based on the NEC. As OSHA focused more on all aspects of electrical safety, the need was created for a consensus document to assist them in preparing electrical safety requirements. The first edition of this document was published in 1979 and was most recently updated as the 2012 edition. The document provides the latest thinking on the subject of electrical safety, particularly in the area of electrical hazards analysis, safe work practices, and PPE. Many parts of the current OSHA regulations 29CFR1910, Subpart S, were derived from the NFPA 70E standard as described in the preamble to the standard.

NFPA 70B is a document whose purpose is to reduce the hazards to life and property that can result from the failure or malfunction of industrial-type electrical systems and equipment. Along with its maintenance guidance, it also addresses electrical safety.

The National Electrical Manufacturers Association (NEMA) has many standards on electrical products and systems. Their product standards have often served as a basis for Underwriters Laboratories' (UL) safety

standards. Both NEMA and UL standards are formulated on a consensus basis and should be considered as minimal requirements.

4.5 Summary

In summary, electrical hazards exist, and will continue to exist, especially in a world of ever-increasing technology. In order to prevent injury and loss of life, everyone should learn to recognize the electrical hazards associated with their respective workplaces and job assignments, and know how to take appropriate precautions to avoid injury. This clause has covered the kinds of injuries that can occur and some true examples of incidents. Remembering these incidents, and telling friends and associates about them, may instill in someone the awareness and discipline that could someday save a life.

There are many reasons why everyone should receive some level of electrical safety training. Familiarity with the OSHA regulations, the NFPA electrical codes and standards, and the IEEE standards can increase safety awareness for all electrical employees, and perhaps may save an employee or friend from injury or death.

5. Establishing an electrical safety program

5.1 General discussion

Before a sports team goes into any game, the coaches prepare a game plan designed to beat the opponent. If all members of the team perform according to the plan, the team has a much better chance of winning. An electrical safety program is much like that game plan. It is a plan designed so that neither workplace conditions, nor the actions of people, expose personnel unnecessarily to electrical hazards. Establishing an electrical safety program, and making sure that employees follow it, can mean “winning the game” against accidental injury or death due to electrical incidents.

5.2 Content of program

An electrical safety program should consider the legal implications of specific guidelines. In the U.S., one legal authority is the Occupational Safety and Health Administration (OSHA). Many other countries have laws that define requirements on which programs must be based. The content of applicable national and local laws must be considered when defining and implementing an electrical safety program.

A complete electrical safety program should contain directives on the following subjects:

a) Management commitment
b) Organizational support
c) Electrical safety policy
d) Energized Electrical Work Permit
e) Training and qualification of personnel
f) Use of protective equipment, tools, and protective methods
g) Use of electrical equipment
h) Authorization of specific work tasks

i) Documentation

j) Oversight and auditing

k) Technical support

l) Emergency preparedness

These items are discussed in more detail in 5.2.1 through 5.2.10.

5.2.1 Management commitment

An electrical safety program may be ineffective if it is not strongly supported at the highest management levels. Corporate management should verbally and visibly support the program and confirm that it is being implemented in the workplace by regularly seeking feedback about the status of the program. Management should seek to understand the cost benefit of the electrical safety program, in both humanitarian and financial terms. The first action management must take is to define the corporate electrical safety policy and identify the line organization(s) to implement that policy. Management should direct that the program include auditing and reporting the results of each audit. Management should also verbally and visibly demonstrate commitment to a safe workplace, making safety a top business priority. Preventing injury should be given a priority that is at least equal to or greater than production, cost, quality, or morale. Management should demonstrate this priority by applying this premise consistently and maintaining safety expectations when confronted with other business pressures.

5.2.2 Organizational support

An organization must be structured to accomplish a business objective. In addition, an electrical organization and a safety organization normally are required to accomplish the business objective. Either the electrical or safety organization (or both) should be designated as the "owner" of the electrical safety program.

The following functions must be managed effectively:

- Management
- Design
- Installation
- Facility operations
- Maintenance
- Training
- Purchasing
- Visitor and contractor liaison and training
- Auditing
- Electrical safety program maintenance
- General industrial safety
- Electrical safety authority

Every effective organization has a hierarchy of authority. The National Fire Protection Association (NFPA) defines the authority having jurisdiction (AHJ) as the organization, office, or individual responsible for implementing a standard. In NFPA regulations governing committee projects, a note following the

definition provides examples of who the AHJ might be. In some jurisdictions, this AHJ is identified easily. In many large organizations, however, managers might not have the expertise to make specific technical decisions. In this case, the manager might delegate the authority to a technical member of his or her organization. The function of the AHJ, therefore, usually rests at a technical level in the organization.

Electrical safety processes are similar to other safety processes. Consequently, the electrical safety program can blend easily with an existing overall safety program and organizational structure. Corporate management should designate one part of the organization to be the focal point, or the authority, for electrical safety. Depending on the size of the company, this focal point could be a department, a committee, or an individual or two. This designee should be assigned, and he or she should accept the responsibility of becoming familiar with the electrical safety regulations and generally accepted standards. The designee should be assigned and accept responsibility to manage the following functions:

— Taking ownership of the electrical safety program
— Being knowledgeable of nationally recognized consensus codes and standards
— Providing guidance for facility configuration management
— Resolving NEC questions
— Establishing and documenting good safe work practices
— Providing technical input for OSHA interpretations
— Defining and implementing electrical training programs
— Defining and implementing procedures
— Providing feedback to management
— Reviewing electrical safety incidents and participating in investigations
— Issuing summaries and lessons learned about electrical safety incidents
— Determining electrical equipment meets appropriate safety standards as evidenced by listing or by special investigation in the case of unlisted equipment.

These functions can be divided into two broad categories for those cases in which the responsibilities would be too great for one group. The first category could be design and installation tasks, and the second category could be operational and maintenance tasks.

5.2.3 Electrical safety policy

A corporate electrical safety policy might be published in a policy manual, or it might be stated as a part of the electrical safety program. A policy statement provides members of the line organization with the necessary guidance to define and implement an electrical safety program. The policy might be stated simply in the following manner:

All electrical facilities shall be installed and maintained in a safe manner. All work involving electrical energy shall be performed in a safe manner. The primary safe work practice is to establish an electrically safe work condition. The policy of this corporation is to implement the requirements found in NFPA 70E, Standard for Electrical Safety in the Workplace.

A basic rule that should be derived from the policy statement is that work on or near any exposed energized electrical conductors or circuit parts should be prohibited, except under justified, controlled, and approved circumstances, knowing that exceptions to this policy may become necessary. For example, measuring voltage is a common and necessary task that involves exposure to energized conductors. As indicated by

some of the cases in Clause 4, however, something can go wrong even during such a common task. Therefore, exceptions to the basic rule should be rigidly controlled. Guidelines for such justification are provided in NFPA 70E-2009, Article 110.8 (1): “Energized electrical conductors and circuit parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works within the Limited Approach Boundary of those conductors or parts, unless work on energized components can be justified according to Article 130.1.”

5.2.3.1 Providing and maintaining electrically safe facilities

The recommended electrical safety policy indicates that “electrically safe facilities shall be installed and maintained in a safe manner.” That statement covers the following concerns, which should be detailed in various company documents:

— Design
— Installation
— Inspection
— Maintenance (breakdown and preventive)
— Standards
— Safety audits of workplace conditions
— Organizational structures
— Technical training and qualifications of personnel
— A technical authority to respond to questions or concerns about design and installation

Facilities and systems must be designed initially and installed to provide a workplace that minimizes exposure to electrical hazards. Complying with established federal, state, and local laws and codes helps to promote safety of installations. After facility start-up, the safety of this environment must be maintained as closely as possible to the initial condition. Following the guidance of nationally recognized standards can help to maximize the safety of facilities.

Electrical equipment integrity is a fundamental part of an electrical safety program. Particular emphasis should be placed on the integrity of enclosures, insulation, grounding, and circuit-protective devices. The primary point is that exposure to hazards can be minimized by proper design, installation, and maintenance of equipment.

Good facility standards and drawings are important elements in installing and maintaining a safe facility. Clause 6 discusses electrically safe facilities in greater detail.

5.2.3.2 Implementing safe electrical work practices

The electrical safety policy suggests that work tasks associated with electrical energy be performed in a safe manner. The following issues should be integrated into written company documentation:

— Avoidance of work on or near energized electrical equipment
— Work and task authorization
— Standards
— Safe work practices and procedures

- Safety training and qualifications of personnel
- Safety audits and self-assessments of personnel activities
- Response to questions or concerns regarding safe work practices in operations and maintenance

Safe electrical work practices are the most important part of the electrical safety program. Most injuries and fatalities are a result of the *actions of people* as opposed to *workplace conditions*. Electrical safety principles such as the following (see NFPA 70E) should be identified and discussed with employees:

- Inspect/evaluate the electrical equipment
- Maintain the electrical equipment's insulation and enclosure integrity
- Plan every job and document first time procedures
- Deenergize, if possible
- Anticipate unexpected events
- Identify and minimize the hazard
- Protect the employee from shock, burns, blast, and other hazards due to the working environment
- Use the right tool for the job
- Assess people's abilities
- Audit these principles

Establish administrative controls in the form of policy, required procedures, and guidelines to direct the activities of personnel whose assignments are such that they could be exposed to electrical hazards. Before any work is performed, execute a hazard/risk analysis, work authorization, and a job-briefing. See Clause 7 for details.

5.2.4 Training and qualification of all personnel

The electrical safety program should require electrical safety training for all personnel. This requirement should include training for every employee, including contractor personnel and/or visitors who might be exposed to electrical hazards. The requirement should provide that all workers be trained and qualified by their own employers. Workers who have not been trained should not be permitted to be near energized equipment until the training has been completed.

Training is an effective strategy to safeguard workers against work-related injuries. Training all employees to be electrical experts would be impractical and unnecessary. However, workers should be trained to know how to recognize electrical hazards, both in the workplace and at home.

Workers should be trained to use electrical equipment normally used to troubleshoot problems such as voltage testing/detecting devices and interpret the results. Workers also should be trained to understand what they are *not* allowed to do.

A procedure created as part of a company's employee safety program should cover basic electrical safety awareness that is applicable to all employees. The document should be used as a tool to help understand hazards and how to avoid exposure to them. This procedure should contain the following information:

— Definitions of electrical safety-related terms
— Electrical safety requirements that are applicable to all personnel
— Resources for more detailed procedures for electrical personnel
— Use of electrical equipment
— Electrical PPE requirements

Workers whose job assignment requires frequent exposure to electrical hazards should be trained as defined in NFPA 70E.

5.2.5 Use of protective equipment, tools, and protective methods

A hazard/risk analysis must be performed before any task is started. The analysis should identify whether or not the worker is or could be exposed to an electrical hazard. The worker should then have the necessary information to determine what protective equipment and tools would reduce the risk to an acceptable level. Clause 8 provides details about additional protective measures for employees.

5.2.6 Use of electrical equipment

A work environment might have many different types of electrical equipment. Fixed electrical equipment normally consists of switchgear, switchboards, control panels, disconnect switches, and wall switches. In addition to fixed equipment, the work environment also contains portable equipment such as power tools, temporary lighting, extension cords, and test equipment. How a worker is exposed to an electrical hazard is heavily dependent upon whether the equipment is fixed or portable. The environment surrounding the electrical equipment impacts the manner in which an employee is or might be exposed to an electrical hazard. A qualified worker should be expected to recognize the different hazard exposure mechanism for electrical equipment. The electrical safety program should contain a procedure providing detailed information about electrical equipment that exists in or on the facility, including how a worker might be exposed to electrical hazards. Clause 9 provides additional information about the use of electrical equipment.

5.2.7 Documentation

Documentation is a significant part of an effective electrical safety program. Documents include work authorization forms, standards, procedures, guidelines, drawings, equipment records, and other legally required forms. These documents are discussed in the appropriate clause, along with the applicable subject matter.

An effective document management system is important to the safe operation and maintenance of a facility. Outdated or erroneous documents cause confusion and delays and frequently are identified as a base cause of electrical-related safety incidents. Document distribution should be managed so that only an up-to-date version is accessible. Documents should be located in the places where they are needed. For instance, single-line diagrams should be available in electrical rooms. More information on the subject of procedures and associated documentation can be found in Clause 7.

5.2.8 Oversight and auditing

Periodically, a company should perform a self-assessment or audit to determine how effectively the written electrical safety program is being implemented. The audit should be realistic and include only factual

information. The purpose of the audit must be to improve the effectiveness of the electrical safety program. Occasionally, the company's safety organization, or even an outside consultant, should be asked to perform an electrical safety audit. A person who not familiar with the facility can discover shortcomings that self-assessors might overlook.

The periodic audit should review the content of the published electrical safety program and be designed to identify potential new or revised requirements. Once weaknesses in the program are identified, the electrical safety authority must take actions as necessary to upgrade the program and notify affected workers of any change.

If an electrical safety-related incident occurs (including near misses), a thorough investigation should be completed to determine the root cause and identify any contributing factor(s). Findings from the investigation must serve as the source of information used to revise affected elements of the electrical safety program. Lessons learned should be discussed with all personnel.

5.2.9 Technical support

A company should have technical support from qualified engineering personnel and/or qualified consultants for its electrical safety program. The technical support personnel could be either in-house or contracted employees. These qualified personnel can provide designs for new facilities and equipment and help the facility solve daily or recurring problems. A qualified engineer or consultant should be familiar with the latest developments in his or her field of expertise. Companies should encourage in-house engineers to join nationally recognized professional organizations related to their fields of endeavor.

5.2.10 Emergency preparedness

An effective electrical safety program is incomplete without a procedure that defines requirements for emergency preparedness. Employees should be trained to be familiar with and understand the need to be prepared for unexpected incidents. Rapid response to an electrical shock or burn injury could mean the difference between the life and death of the victim. Electrical workers should be instructed in first aid and CPR and be provided with refresher training as necessary to remain qualified to assist co-workers. A "standby person" who has access to (and is trained in the use of) an *automated external defibrillator* (AED) is recommended whenever work is to be done by a worker within the Restricted Approach Boundary. It has been demonstrated that the immediate application of an AED to a person whose heart has entered ventricular fibrillation has a greatly increased chance of survival. The plan should provide that workers know the location and phone number(s) of the nearest qualified medical assistance when working on or near live parts. An effective communication method should be available for each work task that involves work on or near live parts. Emergency responders should be taught basic electrical safety to avoid exposure to an electrical hazard should response to an electrical injury be necessary.

6. Providing and maintaining electrically safe facilities

6.1 General discussion

When electrical installations are properly designed, installed, and maintained, workplace conditions should be such that they will not be the cause of an electrical shock, burn, or blast. Well-designed enclosures and proper clearances protect employees under normal and most abnormal operating conditions. Proper maintenance of electrical equipment can reestablish the initial safe condition as the equipment ages. It should always be remembered, however, that when it is necessary for personnel to enter electrical equipment enclosures, many of the protective barriers that the design and initial installation have provided

may have to be removed. In these cases, electrical safe practices that are appropriate to the task should be used. (See Clause 7.)

The four major documents that carry the force of law relative to electrical design, installation, and maintenance requirements in the U.S. are extremely important toward establishing electrically safe environments and workplaces. As was mentioned in Clause 4, the first is OSHA regulations; in particular, 29CFR1910, Subpart S, pertaining to general industry; 29CFR1910, Subpart R, pertaining to special industries; and 29CFR1926, Subpart K, pertaining to the construction industry. There are also some other subparts that contain requirements related to electrical work. The second major document is the NEC, which carries the force of law only when it is adopted by a governing entity. Most governing bodies in the U.S., and even some other countries, have adopted the NEC. The third major document is the NESC, which also carries the force of law only when it is adopted by a governing entity, usually a state utility commission or state public safety commission. Again, most states in the U.S. have adopted the NESC. The fourth major document is NFPA 70E-2009, which provides information on employee electrical safety in the workplace (see Foreword to NFPA 70E for background and origin of the document). The standard includes Chapter 1—Safety-Related Work Practices, Chapter 2—Safety-Related Maintenance Requirements, Chapter 3—Safety Requirements for Special Equipment, and supporting information in annexes.

There are many other good references that cover safe design and installation of electrical equipment and systems. It would be difficult to mention them all. Included among them, however, are the IEEE 3000™ (IEEE 300x.x) series “dot” standards, which are a derivative of the IEEE Color Book series.

It is not the intention of this clause to repeat, in detail, the safety-related design, installation, and maintenance information that is already found in other recognized regulations, codes, and standards. This clause will, however, give an overview of how to find and use the helpful information found in those documents.

6.2 Design considerations

Providing a safe environment and workplace facilities begins with the initial design of a facility, process, or piece of equipment. The design process begins with contacting the customer and thoroughly understanding the customer’s objectives for his facility, including, in particular, the safety concerns. The documents mentioned in Clause 5 and in 6.1 contain requirements for design. These documents, however, are not design specifications, and should be used with care only by qualified personnel.

The *IEEE Color Books*® are excellent sources of information for industrial, commercial, and institutional power system analysis and design, but they are not meant to replace any engineering textbooks and handbooks commonly in use. They are considered to be guides and references on electrical design and analysis, and should be used as such. In particular, the following standards in this series enable analysis and caparison of design options that enable optimization of engineering design solutions to reduce risk from electrical hazards:

— IEEE 141™-1993 [B21] (*IEEE Red Book™,* to become IEEE 3001™ series)

— IEEE 142™-1990 [B22] (*IEEE Green Book™,* to become IEEE 3003™ series)

— IEEE 241™-1990 [B23] (*IEEE Gray Book™*, to become part of IEEE 3001™ series)

— IEEE 242™-1986 [B24] (*IEEE Buff Book™,* to become IEEE 3004™ series)

The NEC is not a design manual for untrained persons. The requirements it contains are often the minimum that are essential to achieve fire protection and safety for the facilities. Many times, however, design specifications need to be even stricter in order to achieve a cost-effective, well-functioning installation. That is why the NEC is intended to be used only by the following qualified personnel:

a) Engineers and designers in the design of electrical equipment and facilities
b) Electrical inspectors and others who exercise legal jurisdiction
c) Insurance inspectors to verify safety of the installation
d) Electrical contractors and electricians to meet installation requirements
e) Instructors to educate and refresh electrical personnel

The NEC contains many requirements to help a design organization develop a safe facility from an electrical standpoint. These requirements cover the following topics:

— Wiring and protection
— Methods and materials
— Equipment for general use
— Special occupancies
— Special equipment
— Special conditions
— Communications systems

For safety purposes, design should take into account the following items:

— Protection against shock, burn, and blast
— Fire protection
— Illumination
— Working space
— Drawings
— Equipment identification
— Grounding and bonding

The NESC is also not a design manual for untrained persons. The NESC covers basic provisions for safeguarding of persons from hazards arising from the installation, operation, or maintenance of (1) conductors and equipment in electric supply stations, and (2) overhead and underground electric supply and communications lines. The purpose of the NESC is to provide rules for the practical safeguarding of persons during the installation, operation, and maintenance of electric supply and communication lines and associated equipment.

The NESC rules cover supply and communication lines, equipment, and associated work practices employed by a public or private electric supply, communications, railway, or similar utility in the exercise of its function as a utility. They cover similar systems under the control of qualified persons, such as those associated with an industrial complex or utility interactive system.

The NESC covers utility facility and functions up to the service point and the NEC covers utilization wiring requirements beyond the service point.

6.2.1 Design for shock, burn, and blast protection

Meeting NEC requirements for electrical equipment installations is only one part of a safe design. The design of electrical equipment should also include features that can reduce the possibility of equipment damage and personnel injury. For example, arcing faults can be very dangerous and destructive. Considerations to reduce the consequences of such faults should be addressed at the design stage.

Power distribution equipment should be designed so that it is easily operated and maintained. It should also be lockable.

Short-circuit analysis or fault-current analysis is very important toward identifying the fault current available at any given point in a system. This is also important in the hazard/risk analysis (see Clause 7) to determine the possible consequences of employee exposure to an electrical arc flash.

Power distribution circuits should be designed to accommodate the user's requirements for maintenance and isolation of loading. For example; the routine maintenance of electrical equipment such as cleaning, testing, and inspection should be possible without a complete shutdown of critical power to certain processes and equipment. Parallel sources or bypass switching to such loads as well as warning signs that identify the danger of energizing equipment from more than one source should be designed and installed for such systems.

The proper grounding of equipment that utilizes electrical energy is essential to protection from electrical shock. The subject of grounding is covered in Article 250 of the NEC and in many IEEE standards.

The environment in which electrical equipment is installed should also be taken into account during design. The deteriorating effects of weather and chemicals can eventually compromise equipment safety features.

6.2.2 Design for fire protection

In addition to providing designed safety against shock, burn, and blast, the workplace should also be designed for fire protection. Fires occasionally develop in electrical equipment due to loose connections, insulation failure, or overload conditions that may not be detected and cleared properly by protective devices. Protection against fire is a good reason to confirm proper design, installation, and maintenance. Selecting equipment that is manufactured to applicable codes and standards, and is listed and labeled properly, helps to reduce the risk of fire in the equipment.

In addition to the design of the electrical system and equipment, there should be fire detection and suppression equipment permanently installed or readily accessible in the facility around or near the electrical equipment. Such equipment could possibly include smoke detectors, sprinkler systems, and portable fire extinguishers. Also, the workplace should be designed so that escape routes are sufficiently wide, clear of obstructions, and well marked. Proper illumination of the paths of egress by normal lighting, emergency lighting, and exit signs is also very important. For more about fire safety, refer to other NFPA standards.

In order to avoid initiating a fire or explosions from an electrical ignition source, pay attention to electrical installations in classified hazardous areas in accordance with Chapter 5 of the NEC.

The proper sizing of conductors is important in order to protect against the overheating of the conductors and their surroundings. Article 310 of the NEC covers this subject.

Overcurrent protection is important to avoid equipment burn-downs when overloads or faults occur. Short-circuit analysis is a major part of establishing adequate fault protection. Overcurrent protection is addressed in Article 240 of the NEC.

Motors and generators need to be protected against overheating so that they do not cause a fire. NEC Article 430 covers motors and Article 445 covers generators.

6.2.3 Illumination

Lighting systems in the area around electrical equipment should be designed to provide adequate illumination of the vertical surfaces of the electrical equipment. Proper illumination is not only important for performing normal tasks, but it is also very important from a safety standpoint when installations are being checked-out at start-up, as well as during maintenance and troubleshooting after being turned over to operations. Poor illumination might be the cause of an electrician putting a tool in the wrong place and creating an arc flash. In a high-energy circuit, this mistake could be fatal. If permanently installed lighting is felt to be inadequate, no work should be attempted in any area that might contain a hazard. Some temporary lighting equipment should be obtained and used at the work location. Perhaps a suggestion should be made to improve the lighting in that area. Emergency lighting should also be installed to provide necessary illumination in order to minimize safety problems during a sudden power outage.

The design of illumination systems is an engineering art and science that is practiced by many electrical engineers with knowledge and experience in this discipline. The Illuminating Engineering Society of North America (IESNA) disseminates knowledge relating to illumination physics, light and vision, measurement, luminaire design, day lighting, light sources, calculations, applications, and codes and standards. The IES has established recommendations for illuminance (density of incident light energy) for a broad classification of visual activities.

6.2.4 Work spaces and working clearances

Electrical equipment should be designed with adequate working spaces both within the equipment and around it. Installations in cramped spaces or areas where accessibility is difficult should be avoided. Working on or near exposed energized electrical parts in cramped spaces is especially dangerous because reflex reactions, such as those from bumping into objects, could cause a person to involuntarily contact the energized parts and receive a shock or instigate a flash. Minimum dimensions for access to, and clearances around, electrical equipment are given in Article 110 of the NEC. Greater working distances may be beneficial in many circumstances, such as if a worker needs to use live-line tools around equipment.

Allow room for future expansion and rearrangement in the initial designs. Although it is usually not possible to predict the future, more often than not, someone will want growth or improvement. Allowing extra space initially helps to avoid the temptation to squeeze things in and possibly create a working-space safety problem in the future.

6.2.5 Drawings

Drawings should be created initially not only for installation purposes, but also for operation and maintenance purposes after the construction forces leave. A company should have its own standards to govern the creation and maintenance of electrical drawings. Such drawings are important to safety in that they help personnel understand the equipment on which they are working and how that equipment relates to the rest of the electrical system.

Perhaps the most important drawing from an electrical safety standpoint is the single-line or one-line drawing. The single-line drawing gives a quick overview of the power sources and the sequence of disconnecting means. The single-line drawing is essential during maintenance procedures since it is critical for safe planning of lockout/tagout and circuit isolation procedures. Single-line drawings used for the safe electrical operation of the power system should be free of extraneous engineering information, such as

conductor sizes and relay settings. Information that could be included are such items as short-circuit available current, nominal voltage, and incident energy.

As-built drawings are especially important from a safety standpoint. Accurate as-built drawings reduce the likelihood of accidents by providing reliable information on how the system was actually installed, which often varies from the original design intent. As-built drawings also add some level of certainty that the electrical system will function as designed.

The electrical plan drawing is another document that is important for maintenance and future modifications after installation, since it shows the location of electrical equipment and disconnecting means. This drawing is particularly valuable to new personnel, contractors, and visitors who are unfamiliar with a facility. The plan drawing should also be the document that shows embedded electrical conduits and hidden wiring. Knowing the approximate location of such concealed hazards provides the opportunity to protect personnel against the unexpected.

It is important that such drawings, particularly the single-line drawings, be accurate and easily accessible at all times.

6.2.6 Equipment identification

Every facility should have a standard that covers the design and use of identification plates and tags for electrical equipment in a facility. Good identification is very important toward safely energizing and de-energizing equipment. In particular, proper identification is an extremely important element toward ensuring that equipment on which personnel work has been truly placed in an electrically safe work condition. An “electrically safe work condition” is defined in Clause 7. The symbols used on drawings should be from a nationally recognized standard so that they are understood by both in-house and contractor personnel and should be consistent throughout the facility. IEEE has several such standards.

6.2.7 Grounding and bonding

It is extremely important to electrical safety that equipment and structures be properly grounded and bonded. All too often, these items are left as afterthoughts when new facilities and equipment are being installed. Grounding and bonding should be planned and designed with the same importance as the other parts of the electrical system.

The terms *grounded* and *bonded* are well defined in the NESC and in the NEC. Bonding is “the electrical interconnecting of conductive parts, designed to maintain a common electrical potential.” This definition is self-explanatory and implies that the conductive path should be adequately sized, and connections properly installed, in order to maintain a path with impedance as low as possible. The term *bonding* obviously is not exclusive to grounding systems.

Grounded means “connected to, or in contact with, the earth, or connected to some extended conductive body that serves in place of the earth.” The earth or the other conductive body is known as the *ground.* When used as a verb, grounding is the act of establishing the aforementioned connection and conductive body. When used as an adjective, grounding describes something that is used to make the connection to ground.

There are two different kinds of permanent grounding relative to electrical work. The first kind is system grounding. System grounding is attaching at least one point of the normally current-carrying electrical path to ground, either solidly or through an impedance. The system ground affects performance of the electrical system, making it more stable and predictable. From a safety viewpoint, system grounding limits the potential difference between uninsulated objects in an area, helps limit the magnitude of overvoltages due

to transients, and provides the reference point for the return of fault currents so that faults can be isolated quickly.

Equipment grounding is intended for safety purposes and is the act of bonding all non-current-carrying conductive objects together to create a low-impedance conductive body (or path) to a ground reference. Among the safety purposes for equipment grounding are the following:

a) Providing a path for the safe conduction of static and lightning currents, to reduce the possibility of fire or explosion;
b) Providing a permanent low-impedance path for fault currents to return to the system ground when these currents get off of the normal current-carrying path;
c) Providing a temporary low-impedance path as a protective measure in case of accidental energization during maintenance activities. This type of grounding is often called temporary personal protective grounding. Since this type of grounding is associated with safe work practices, it is discussed in Clause 7.

More about grounding and bonding can be found in IEEE Std 80™, IEEE Std 142™-2007 [B22], and IEEE Std 1100™-2005 [B28].

6.3 Installation safety requirements

As was mentioned in 6.1, installation safety requirements are contained in several documents. The NEC is undoubtedly the document that is most familiar to electrical equipment installers. Installers should do the following things to provide an electrically safe facility:

a) Install equipment in accordance with the operating diagrams, manufacturer's instructions, and other design documents.
b) Implement the requirements of the NEC.
c) Install equipment in a neat and workmanlike manner.
d) Challenge design information that appears to disagree with the NEC.

6.4 Safety and fire protection inspections

After installation of new equipment and facilities or the major modification of existing equipment and facilities, a safety and fire protection inspection should be initiated by the facility custodian, whether it is required or not. It is also prudent, and often cost effective, to do periodic inspections while the installation or modification is being performed in order to detect problems before they become difficult to correct. At this time, one should look for exposed conductors, nationally recognized testing laboratory (NRTL) labels, NEC violations, easily understood identification, ease of operability and maintenance, tight working spaces, adequacy of lighting, and other issues that might compromise safety. In some jurisdictions, it is also required by local law that official inspections be conducted by an authorized inspection agency.

Periodic safety inspections and audits should be conducted after operations begin to verify that conditions remain as safe as they were initially.

6.5 Preplan for safe maintenance

The design of a facility and its electrical equipment should include consideration for future maintenance, see 6.2. In order to remain in good, safe condition, the electrical equipment and facilities must be maintained properly. Dust and dirt, damaged enclosures and components, corrosion, loose connections, and reduced operating clearances can be the cause of employee injuries. Some of these conditions can also lead to fire. A thorough, periodic preventive maintenance plan should be established as soon as new facilities and equipment are installed.

Local procedures should be created as soon as possible to cover the maintenance of electrical equipment. Most of this information can be obtained from recognized standards and manufacturers' literature. Proper operation and maintenance are important to electrical safety because when electrical equipment does not function as designed or planned, the results may be unexpected. Many injuries and fatalities have occurred when the unexpected happened.

NFPA 70B is an excellent guide to recommended practices for maintenance of electrical equipment. It also contains the "why's" and the "wherefore's" of an electrical maintenance program, as well as guidance for maintaining and testing specific types of electrical equipment. In addition, it contains information in its appendix regarding the suggested frequencies for performance of maintenance and testing. This is a good document to review while facilities are being installed.

The InterNational Electrical Testing Association (NETA) also produces a standard to address the suggested field tests and inspections that are available to assess the suitability for continued service and reliability of electrical power distribution equipment and systems. The document is ANSI/NETA MTS-2011 [B3].

See more about the maintenance of electrical equipment in IEEE Std 3007.2™-2010 [B30].

6.6 Repairs and replacement parts

When maintenance requires repairs or replacement parts, it is important to keep in mind the potential safety consequences of poor workmanship or inadequate repairs/fixes by unqualified workers. These can negate safety features that were a part of the original design.

Qualified persons should perform repairs in accordance with the manufacturer's instructions and drawings. Using unqualified or unknown persons to perform repairs, without checking out their credentials, is asking for trouble. If there are no in-house qualified persons, there are many qualified service organizations, both independent types and those that are associated with a particular manufacturer. Before agreeing to any contracts, it is important to make sure that the contractor has good electrical safety qualifications. If the contractor's safety qualifications are unsatisfactory, the use of that contractor should be refused until they furnish an OSHA- and NFPA-70E-compliant program. Accidents on the job site usually cause management to become involved, even though there were no company personnel hurt. This may result in lawsuits against the host company, even though the host company may not be directly involved.

Using the wrong replacement part can also negate the original safety features. Be sure to check manufacturer's literature for the proper replacement parts. Be aware that there are counterfeit parts on the market, and be careful not to use them. Know your suppliers and where they get their parts. When proper parts are no longer available, ask the original manufacturer for a recommendation. Of course, if the inquiry involves old or obsolete equipment, a manufacturer will often suggest replacing it with their modern equipment. Many times, that would be a wise decision to avoid repetitive problems, but one must make decisions based on many factors, including budget constraints, equipment availability, equipment compatibility, and above all—safety considerations. The manufacturer can provide guidance to these issues as well as a qualified, reputable service and repair company.

7. Safe electrical work practices

7.1 General discussion

Another major objective of the electrical safety program is to establish safe electrical work practices. No matter how well a facility is designed and built, careless actions of personnel can still result in injury or death. Safe practices involving electrical work are necessary in all workplaces in order to enable employees to recognize electrical hazards and minimize exposure to them. These days, excluding overhead lines, there are very few cases in which equipment is designed and installed without adequate physical protection against electrical hazards to personnel. Even overhead lines are essentially “protected” from personnel due to their elevation. Most exposure comes during start-up and check-out, and during maintenance, troubleshooting, and modification.

Safe practices are the most important area of the electrical safety program on which to concentrate. A significantly greater number of injuries and fatalities are the result of poor or careless practices than the result of poor equipment conditions. Look back at some of the case histories in Clause 4.

It is not the intention of this clause to repeat all of the safe work practice information already found in other nationally recognized regulations, codes, and standards. This clause will however give an overview of the helpful information related to safe practices that can be found in those documents.

7.2 Training

The electrical safety program can document all of the greatest electrical safe practices in the world, but if this information is not distributed to and implemented by the persons who are exposed to the electrical hazards, the information is almost useless. This is where training comes in. Personnel should be trained to understand the content of the rules, why they exist, and how to implement them in the field. Federal law, in OSHA regulation 29CFR1910.332, requires that employees who face a risk of electrical shock that is not reduced to a safe level by electrical installation requirements, be trained in, and be familiar with, electrical safety-related work practices that pertain to their respective job assignments. Training is permitted to be either in the classroom or on the job. A combination of classroom and on-the-job training provides the best learning results.

Training on safety-related work practices should cover all personnel, not just persons associated with the electrical segment of the business. In this modern day of technology, so-called “unqualified” persons are surrounded by large quantities of electrically powered utilization equipment. Even though they do not necessarily need to know the construction or how things operate internally, they do need to know about the possible electrical hazards and how to avoid those hazards. Therefore, everyone in the workplace should have some degree of electrical safety training so that they can be qualified to perform their assigned tasks. Part of this qualification should cover the electrical safety aspects of their assignments.

People need to understand the reasons why they should follow electrical safety-related procedures, standards, and practices so that they will approach such work with the proper attitude and caution.

As mentioned in 5.2.10, electrical personnel should also be trained in emergency procedures, such as methods of releasing victims, first aid, AED use, and CPR, since they might someday have a need for these techniques in their job assignments.

7.2.1 Qualified vs. unqualified persons

Among the first items discussed in NFPA 70E-2009, Chapter 1, Section 110.6, are qualified and unqualified personnel. The definition of a qualified person, found in the introduction of NFPA 70E, is "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved." In order to obtain the skills and knowledge of electrical equipment, a person must be trained, not only on the technical and mechanical aspects of the equipment or a specific work method, but also to recognize and avoid the electrical hazards of working on or near exposed energized conductors or circuit parts. Obviously, an unqualified person is one who does not meet the criteria for whatever equipment is being worked on, or for the activity that is being performed.

The terms *qualified* and *unqualified* are often misunderstood. Some people think that to be electrical safety qualified, one must be a fully qualified electrician who has had a long list of electrical training courses. In reality, a person may be electrical safety qualified to perform only a limited number of tasks on or near specified electrical equipment. Take, for example, a tree trimmer. He or she certainly is not a fully qualified electrical worker as we might think of one, but he or she should be electrical safety qualified to work near overhead electric lines and understand the electrical hazards associated with tree trimming.

NFPA 70E-2009, Chapter 1, Article 110, addresses the subject of training for qualified persons (i.e., electrical safety qualified). According to that document, they shall

- Be trained in, and knowledgeable of, the construction and operation of the equipment or a specific work method;
- Be trained to recognize and avoid the electrical hazards that might be present with respect to such equipment or work method;
- Be familiar with the proper use of special precautionary techniques, PPE, insulating and shielding materials, and insulated tools and test equipment.

Persons permitted to work on or near exposed conductors and circuit parts must also be trained in and familiar with the following:

- The skills and techniques necessary to distinguish exposed live parts from other parts of electrical equipment;
- The skills and techniques necessary to determine the nominal voltage of exposed live parts;
- The approach distances specified in Table 130.2(C) of NFPA 70E-2009, Chapter 1, Article 130, and the corresponding voltages to which the qualified person will be exposed;

NOTE—The distances in Table S-5 of 29CFR1910.333(c) appear to pertain only to overhead lines. NFPA 70E-2009 attempts to also clarify safe approach distances for other kinds of electrical installations.

- The decision-making process necessary to determine the degree and extent of the hazard and the PPE and job planning necessary to perform the task with minimal safety risk.

The European standard EN 50110-1 defines three levels: *skilled person, instructed person,* and *ordinary person*.

A *skilled* person and *instructed* person must possess levels of competence, officially confirmed and authorized by a training certification, periodically updated and checked, evaluating also the work conduct.

The *skilled* operator has relevant education, knowledge, and experience to enable him or her to analyze risks and to avoid hazards that electricity could create. The *instructed* operator is adequately advised by skilled persons to enable him or her to avoid dangers that electricity could create.

The *ordinary* person is neither a skilled person nor an instructed person.

7.3 Electrical safety controls

Electrical safety controls include both administrative controls and self-controls. The administrative controls are specific facility or company rules regarding the conduct of work on or near electrical conductors and circuit parts. Administrative controls include many items, such as training and qualification of personnel, a work request system, job planning, work authorization documents, procedures, and audits. These subjects are discussed in several other parts of this recommended practice. These controls are often thought of as paperwork, but they provide a logical, organized plan to address potentially hazardous electrical tasks. Self-controls are those steps that one takes to protect one's own safety and are discussed in 7.3.3.

7.3.1 Procedures

It is important to develop in-house standard procedures in order to provide direction to employees regarding the safety requirements and precautions to take while working within the Limited Approach Boundary of electrical equipment. This is especially true when personnel will be, or may be, exposed to energized electrical conductors and circuit parts. These procedures should be designed as easily used references for the kinds of tasks in which an employee could be exposed to an electrical hazard. These procedures should address work on electrical equipment at all voltage levels. In some facilities, these procedures are made requirements that carry penalties for violating them.

These procedures are the interface between the "planning" and the "doing." They are designed to provide an awareness of both electrical hazards and discipline for all personnel who are required to work in an energized electrical environment. A procedure on safe practices on or near electrical conductors allows for an instant audit of what is required to perform work on or near energized electrical conductors and circuit parts. A detailed procedure for the normal activity on each different type of major electrical equipment, and for the performance of electrical tests that may be done on a regular basis, helps identify hazards and enables them to be eliminated or controlled. Advance planning and preparation for the unexpected can minimize the detrimental effects of hazards that might still occur. Adherence to the procedures provides discipline for handling general work, and prepares personnel to handle the few unforeseen special jobs that may develop.

Safe work methods must be stressed to all personnel. No shortcuts or spur-of-the-moment activity is to be permitted. Work on or near energized conductors and circuit parts that develops, and which has not been previously identified by a procedure, should be reviewed, and a special procedure should be written prior to the performance of the work.

Both general and job-specific procedures are needed due to the large variety of potentially hazardous electrical tasks that may be encountered in a facility. A general procedure would cover such routine things as opening electrical equipment enclosure doors and taking voltage measurements. See Figure 5 for an example of an absence of voltage test on a medium-voltage switch. Job-specific procedures are needed for unusual or unexpected tasks, or for work on specific pieces of unusual electrical equipment.

All procedures should be prepared by qualified electrical personnel who are familiar with a given facility or plant following a standard format that addresses the controls of the electrical safety program. A typical outline should include information as shown in 7.3.1.1.

Figure 5—Absence of voltage test on medium-voltage switch

7.3.1.1 Safe practices procedure typical outline

Typical outline of an electrical safe practices procedure is as follows:

- *Title*. The title identifies the specific equipment where the procedure applies.
- *Purpose*. The purpose is to identify the task to be performed.
- *Qualification*. The training and knowledge that qualified personal shall possess in order to perform particular tasks are identified.
- *Hazard identification*. The hazards that were identified during development of the procedure are highlighted. These are the hazards that may not appear obvious to personnel performing work on or near the energized equipment.
- *Hazard classification*. The degree of risk, as defined by the hazard/risk analysis, is identified for the particular task to be performed.
- *Limits of approach*. The approach distances and restrictions are identified for personnel access around energized electrical equipment.
- *Safe work practices*. The controls that shall be in place prior to, and during the performance of, work on or near energized equipment are emphasized.
- *Personnel protective clothing and equipment*. The minimum types and amounts of protective clothing and equipment that are required by personnel to perform the tasks described in the procedures are listed. Personnel performing the work shall wear the protective clothing at all times while performing the tasks identified in the procedure.

— *Test equipment and tools*. All the test equipment and tools that are required to perform the work described in this procedure are listed. The test equipment and tools shall be maintained and operated in accordance with the manufacturer's instructions.

— *Reference data*. The reference material used in the development of the procedure is listed. It includes the appropriate electrical single-line diagrams, equipment rating (voltage level), and manufacturer's operating instructions.

— *Procedure steps*. The steps required by qualified personnel wearing personal protective clothing and using the approved test equipment to perform specific tasks in a specified manner are identified.

— *Sketches/drawings*. Sketches or drawings are used, where necessary, to properly illustrate and elaborate specific tasks.

7.3.2 Work authorization

Before beginning any work, particularly in an existing operating facility, a person should receive a request to do the work from a person with the authority to request this work, thoroughly plan the job, review the job plan with the requester, and obtain permission from the facility manager to proceed with the work. Some kind of work authorization document is advisable so that everyone who may be affected is aware of what is going on. In addition to approvals, this document could contain a checklist of safety items that should be considered before proceeding with the work. The work authorization document forces people to think about the safety aspects of the job. This concept applies to all kinds of work, not just electrical.

Again, as was stated in Clause 4, when performing electrical work in a country other than the U.S., make sure that any laws of the country that may be applicable to the job being performed are known.

7.3.3 Self-controls before each task

Electrical safety self-control is a process by which one performs his or her own safety analysis before beginning any task. This is the first step of a personal hazard/risk analysis. It can be accomplished by simply asking questions of oneself. If one can honestly answer "yes" to all of the following questions, he or she has done a good job of controlling his or her own safety. If one responds "no" to any of the questions, there is a safety concern that he or she should address before proceeding with the work.

a) Do I fully understand the scope of the task?

b) Am I trained and qualified to perform this task safely?

c) Have I performed this task before; if not, have I discussed the details with my supervisor?

d) Have I thought about possible hazards associated with this task and taken steps to protect myself against them?

e) Have I determined whether or not I will be near exposed energized parts?

f) If I am going to be exposed to energized parts, can they be put into an electrically safe work condition? [If "No," skip to item i).]

g) Did I verify, using appropriate protective and test equipment, that the conductors or equipment are in a de-energized state?

h) Have I applied a lockout/tagout device?

i) If I will be exposed to energized parts, do I know what voltage levels are involved?

j) Do I know the safe approach distance to protect against the electrical shock hazard?

k) Do I know the safe approach distance to protect against the electrical arc/flash hazard?

l) If a permit for energized work is required, have I obtained one?

m) Do I have the proper electrical PPE for this type of energized electrical work?

n) Do I have the appropriate voltage-rated tools and test equipment, in the proper working order, to perform this task?

o) Have I considered and controlled the following factors in my work environment?

   1) Close working quarters

   2) High traffic areas

   3) Intrusion/distraction by others

   4) Flammable/explosive atmosphere

   5) Wet location

   6) Illumination in the area

p) Do I understand that doing the job safely is more important than the time pressure to complete the job?

q) Do I feel that all of my safety concerns about performing this task have been answered?

This set of self-control questions makes the employee slow down and think about what he or she is going to do. Applying these controls can significantly reduce the probability of the employee being injured or killed while performing an electrical task.

7.3.4 Identifying hazardous tasks

All work within the Limited Approach Boundary near electrical equipment should be evaluated to determine whether or not the work exposes personnel to an electrical hazard, and if so, what the magnitude of the hazard is. This evaluation is called a *hazard/risk analysis*. For example, a small task might be to put a nameplate on an electrical equipment enclosure door. Now, if the nameplate is put on using adhesive with the enclosure door closed, no hazard is apparent. However, if a person must drill into the enclosure or open the door to attach the nameplate with rivets or screws, there is exposure to energized conductors.

No matter how simple a task might first appear to be, a hazard/risk analysis and the electrical safety self-control questions should be applied. One example of a hazard/risk analysis is given in Annex F of NFPA 70E-2009.

7.3.4.1 Typical hazardous tasks in electrical work

The following tasks are some examples of possible exposure to energized conductors:

a) Measuring, testing, and probing electrical system components

b) Working near battery banks

c) Opening electrical equipment enclosure doors or removing covers

d) Inserting or pulling fuses

e) Drilling, or otherwise penetrating, earth, walls, or floors

f) Pulling conductors in raceways, cable trays, or enclosures

g) Lifting leads or applying jumpers in control circuits

h) Installing or removing temporary grounds

i) Operating switches or circuit breakers

j) Working inside electronic and communications equipment enclosures

7.3.5 Evaluating the degree of hazard

Each of the tasks mentioned in 7.3.4.1 should be evaluated for the degree of electrical hazard involved. For example, opening an enclosure door of a 120 V control panel containing many relays and terminals does expose a person to an electrical hazard. But the probability of serious injury may be small due to the configuration of the equipment, the lower voltage and lower fault current capacity. Whereas opening the door or cover of an energized, 13.8 kV primary disconnect switch enclosure exposes a person to a much greater danger due to the higher voltage and larger fault current capacity. Different procedures, PPE, approvals, and support personnel would be required.

7.3.6 Actions to minimize or control the hazard

Obviously, it is most desirable to minimize all hazards to the extent possible. The best way to do that is to rethink the purpose of the job and why it cannot be accomplished by establishing an electrically safe work condition (see 7.4.1). If the answer is "inconvenience" or "saving a little time," then the answer is not good enough. First of all, it would violate the intention of OSHA laws (see 7.4.2). Secondly, the possible consequences if something went wrong should be considered (see 4.4).

When it is not possible or feasible to establish an electrically safe work condition, it is extremely important that work on or near exposed energized electrical conductors and circuit parts be thoroughly planned and strictly controlled. Work shall be done only by qualified personnel who have been trained to use safe practices and protective equipment.

7.3.7 Permit for energized work

In addition to work authorization documents, it is desirable to have a special permit system to give specific permission to work on or near energized electrical conductors or circuit parts. This permit would indicate the following items that are required before working on or near exposed energized electrical conductors or circuit parts:

a) A description of the circuit and equipment to be worked on and their location

b) Justification for why the work must be performed in an energized condition

c) A description of the safe work practices to be employed

d) Results of the shock hazard analysis

e) Determination of shock protection boundaries

f) Results of flash hazard analysis

g) The Flash Protection Boundary

h) The necessary PPE to safely perform the assigned task

i) Means employed to restrict access of unqualified persons from the work area

j) Evidence of completion of a job briefing, including a discussion of any job-specific hazards

k) Energized work approval (authorizing or responsible management, safety officer, or owner, etc.) signature(s)

In the past, this was called a *hot work* permit. Today, it is called an *Energized Electrical Work Permit*. (See 7.5.)"

7.4 Working on or near de-energized equipment

The definition of the term *de-energized* can be found in the *IEEE Standards Dictionary: Glossary of Terms & Definitions* [B20] and in several other documents. It is defined as "free from any electrical connection to a source of potential difference and from electric charge; not having a potential different from that of the earth."

At first thought, some people might think that they are safe if the electrical equipment on which they are going to work is de-energized. However, things are not always as they appear. The unexpected happens. A person should think, "What if...?." What if the wrong disconnect switch was opened? Or, since you can't watch the switch and work at the same time, what if someone turns the switch back on while you are busy working? What if a source of voltage from another circuit somehow gets accidentally connected onto the conductors on which you are going to work? What if a very large induced voltage is present? The point is that there are several things to consider for safety while a person is working. De-energizing is only one part of creating an electrically safe work condition.

7.4.1 Establishing an electrically safe work condition

In the past, the methods that electrical personnel followed to protect themselves were lumped into a term called *clearance procedures.* In some cases, clearance simply meant permission to work on a particular system, whether it was energized or not. In other cases, clearance meant taking measures to verify that equipment is de-energized, and to reinforce those measures with formal safeguards against altering that de-energized status for as long as clearance is required. The latter use of the word *clearance* is closer to the hazardous energy control requirements in place today. The term *clearance* is falling out of use in modern electrical safety terminology because it does not mean safety. Clearance (for work) is defined in 29CFR1910.269 as "authorization to perform specified work or permission to enter a restricted area." Today, for safety purposes, the phrase "establish an electrically safe work condition" is preferred. An electrically safe work condition is defined in NFPA 70E-2009, Article 100:

"A state in which an electrical conductor or circuit part has been disconnected from energized parts, locked/tagged in accordance with established standards, tested to ensure the absence of voltage, and grounded if determined necessary."

NFPA 70E-2009, Chapter 1, Article 120, addresses the specific requirements for achieving an electrically safe work condition as quoted below:

"An electrically safe work condition shall be achieved when performed in accordance with the procedures of 120.2 and verified by the following process:

a) Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to-date drawings, diagrams, and identification tags.
b) After properly interrupting the load current, open the disconnecting device(s) for each source.
c) Where it is possible, visually verify that all blades of the disconnecting devices are fully open, or that drawout type circuit breakers are withdrawn to the fully disconnected position.
d) Apply lockout/tagout devices in accordance with a documented and established policy.

e) Use an adequately rated voltage detector to test each phase conductor or circuit part to verify that it is de-energized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine that the voltage detector is operating satisfactorily.

f) Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them. Where it could be reasonably anticipated that the conductors or circuit parts being de-energized could contact other exposed energized conductors or circuit parts, apply ground connecting devices rated for the available fault duty."

When non-drawout, molded-case circuit breakers are being used as the disconnecting device mentioned in item b), visual verification of an open circuit, as suggested in item c), cannot be made. One technique that could be used to verify true opening is to have a voltmeter, or other voltage-indicating device, applied as safely as possible somewhere away from the breaker enclosure itself on the load side of the breaker before the breaker is opened. Always try to place the voltmeter at a point where exposure to energized conductors is minimized. Then have someone watch the meter as the breaker is being opened. Simultaneous opening of the breaker and disappearance of voltage is generally a good indicator of disconnection. If that cannot be done, the next best way is to measure load-side voltage (using safe practices and appropriate protective and test equipment), remove the meter, open the breaker, and measure again immediately. With multiple pole systems, all load-side poles should be verified to have voltage prior to disconnection. Again, apply a voltmeter to one of the poles. After the breaker is opened and the first pole is verified, move the meter, as safely as possible, to verify de-energization of the other poles. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. This step is required to assure that one set of contacts of any phase on the breaker has not welded together. Before and after each test, determine that the voltage detector is operating satisfactorily.

CAUTION

1) Always test the functionality of the voltmeter before and after any verification of the absence of voltage.
2) Flash protection may be needed during these operations, depending upon the results of the hazard/risk analysis.

Working on or near electrical equipment without establishing the electrically safe work condition discussed in the preceding paragraph is taking the risk of having an electrical incident, injury, or fatality. Sometimes such risks are necessary due to the nature of the task or the facility. Taking time to evaluate such risks and use the appropriate precautionary measures is also necessary.

A good basic rule to follow can be stated as follows:

All electrical circuit conductors bare or insulated are assumed to be energized until proven otherwise. They shall be de-energized, locked out, and tested for the absence of voltage before working on them or near them. Work on or near electrical circuit conductors and circuit parts may only be performed by trained and qualified personnel who have been authorized to do the work, using appropriate safe practices, personal protective equipment, tools, and test equipment.

Of course, from a practical standpoint, there is a need to have exceptions to this basic rule. For example, taking a voltage measurement is a common task during which a person is exposed to bare energized electrical conductors. Electrical safety measures for such exceptions should be thought about well in advance of any work and made a part of the electrical safe practices procedures. Included in these measures should be a hazard/risk analysis, as explained in 7.3.4 to 7.3.7, and approval from appropriate levels of supervision and management.

7.4.2 Hazardous energy control (lockout/tagout program)

Hazardous energy control is not optional, it is required by law for all employees who work on de-energized equipment where there is potential for injury if the equipment is unexpectedly re-energized. This is an extremely important part of the overall electrical safety program, not only because it is the law, but also because it is a key effective method toward providing for employees the electrically safe work condition described in 7.4.1. It is often called a *lockout/tagout program*.

OSHA regulation 29CFR1910.333(b)(2) states: "While any employee is exposed to contact with parts of fixed electrical equipment or circuits which have been de-energized, the circuits energizing the parts shall be locked out or tagged out or both in accordance with the requirements of this paragraph." That paragraph covers the following subjects:

a) Establishment and maintenance of written procedures for lockout/tagout
b) Establishment of safe procedures for de-energizing equipment
c) Requirements for the use of locks and tags
d) Verification of the de-energized condition
e) Requirements before re-energizing the circuits

This means that a hazardous energy control program shall be established to cover all employees whose jobs could possibly expose them to energized electrical conductors or circuit parts.

Hazardous energy control of electrically operated equipment is important to nonelectrical workers also. Consider the following examples:

— Two mechanics working on a crane runway were knocked 40 ft to the floor below when a control-circuit failure caused the crane to start unexpectedly.
— A pipe fitter was scalded when an operator depressed the "open" button on a motor-operated valve.
— A two-man cleanup crew was buried in a storage silo when a conveyor was started accidentally.
— A hopper gate closed on the torso of a welder who was repairing the hopper lining.

All of these accidents have a common denominator. Although none involved electricians, nor electric shock or electrocution, all were electrically initiated. Furthermore, none of these incidents would have occurred if proper electrical energy control procedures had been in effect.

A hazardous energy control procedure is a part of providing an electrically safe work condition for employees. This procedure is applicable to work on electrical equipment at all voltage levels, not just for higher voltage systems.

Hazardous energy control procedures, in the electrical business, are often referred to as lockout/tagout procedures. There are several existing documents in which lockout/tagout procedures are discussed in detail. ANSI/ASSE Z244.1 is a document that provides good guidance for establishing lockout/tagout procedures; it has a sample lockout/tagout procedure in its appendix.

It is quite obvious that the Federal government is serious about control of hazardous energy in the workplace. OSHA regulation 29CFR1910.147 covers hazardous energy control in general and includes all kinds of hazardous energy, not just electrical. This document also contains a sample of a minimal lockout/tagout procedure. OSHA 29CFR1910.333 is specifically aimed at lockout/tagout for electrical work in general industry. OSHA 29CFR1926.417 discusses lockout and tagging of circuits for the

construction industry. OSHA 29CFR1910.269 discusses lockout/tagout requirements for power generation, transmission, and distribution type work.

Lockout/tagout practices and devices, including training, retraining, equipment, and procedures, are discussed in NFPA 70E.

Some detailed guidance toward establishing a lockout/tagout program is provided in 7.4.2.1 through 7.4.2.12.

7.4.2.1 A realistic approach to lockout/tagout

A lockout/tagout program should include provisions for issuing formal documentation (sometimes called a *permit*) so that controls are in effect and cannot be removed until it is confirmed that all personnel are no longer exposed to hazards. At first thought, it might appear that the ideal program would rigidly require that no work ever be undertaken on any equipment unless a permit is in effect. Such an inflexible policy would not only be unrealistic from an efficiency standpoint, but could create hazards equal to or greater than those that the program is intended to minimize. Immediate action may be necessary in an emergency. There may not be time to procure a formal permit. Therefore, the lockout/tagout program should include a provision that some small, noncomplex, or emergency jobs can utilize an individual undocumented lockout/tagout. Conditions under which an undocumented lockout/tagout can be used are given in 29CFR1910.147.

To be effective, a lockout/tagout program should be written in specific rather than general terms. Including unrealistic requirements or wording that is difficult to understand could damage the credibility of the program. A key element in the success of any lockout/tagout program is employee awareness that no violation of the program is acceptable.

A workable lockout/tagout program, then, is one that acknowledges reality without compromising safety. The program should not obstruct or delay work, but should provide an orderly method for expediting effective lockout/tagout.

7.4.2.2 Employee indoctrination and participation

All employees should be provided with, or have easy access to, a copy of the plant’s lockout/tagout program. New employees should receive thorough indoctrination in the program. This indoctrination is, perhaps, even more important for production employees than for maintenance employees. Maintenance workers work intimately with the lockout/tagout program, acquiring familiarity in the course of their normal duties. For many production workers, though, direct involvement in the lockout/tagout program is minimal, and many accidents are the direct result of production employees operating equipment in violation of the plant’s lockout/tagout program. For this reason, it is a good idea to devote regularly scheduled safety meetings as refreshers for the lockout/tagout program.

The plant’s personnel policy should stipulate that any violation of the plant lockout/tagout program is considered a serious infraction of company rules and is subject to severe disciplinary action, up to and including termination of employment. More important, though, is obtaining the cooperation of employees to make the program work. Employees should be encouraged to feel that the lockout/tagout program is a personal tool for them to use to protect themselves from injury or death.

7.4.2.3 Padlocks and warning tags

Any lockout/tagout program should require that disconnect switches, circuit breakers, fuse holders, etc., be locked out and identified with a warning tag to indicate that the status of the equipment is not to be altered. Preferably, locking and tagging should be done by a qualified electrician, in conjunction with operations

personnel, to open the proper disconnecting means and perform all the required operations. Such a policy ensures smooth shutdown and restart with minimal safety risks.

Requiring that all locking and tagging operations be performed by qualified electricians, however, is unjustified in many types of manufacturing industries. This situation is especially true in light manufacturing industries because many jobs performed by unqualified personnel are of brief duration and are on equipment for which safety can be achieved in a simple, straightforward fashion. With proper training, unqualified personnel can execute many simple lockout/tagouts with minimal safety risk.

Special instruction is essential for unqualified employees who are authorized to execute electrical lockout/tagouts. It is especially important to provide specific instructions in electrical safety procedures, emphasize practices to be avoided, and call attention to specific operations that do not effectively yield an electrically safe work condition.

Employees who are expected to execute lockout/tagouts should be issued a supply of padlocks and warning tags. If the lockout/tagout program allows or requires unqualified personnel to execute electrical lockout/tagouts, it should stipulate that assistance from the plant's electrical department be enlisted any time there is doubt as to what constitutes proper lockout/tagout.

7.4.2.4 Composition of the warning tag

Warning tags should be color-coded and prominently proclaim that the status of the equipment to which the tag is affixed must not be altered. ANSI/NEMA Z535.5 provides guidance on accident prevention tags. Space should be provided on the tag for the name of the person who applied the tag. Except as noted in 7.4.2.5, this person is the only one authorized to remove the tag. Space should also be provided on the tag for identifying the equipment that has been locked and tagged out (e.g., No. 3 air compressor), and the time and date when the tag was placed. To minimize confusion in executing complex lockout/tagouts, an entry on the tag should identify the component of the electrical system to which the tag is affixed (e.g., 480 V air circuit breaker B-9). It is also desirable to provide spaces for indicating the nature of the work to be performed and for additional comments.

7.4.2.5 Personalized padlocks

All padlocks issued to an individual should be commonly keyed, but it is imperative that no two persons be issued padlock sets that can be operated by the same key. Designated supervisors can retain master keys for all padlocks. A documented procedure within the lockout/tagout program should clearly define the details for removing a lock and/or a tag when the person who installed them is not available. Personnel shall be trained on the use of such a procedure. The procedure shall include the following:

a) An attempt to locate the person who installed the lockout/tagout device.

b) Verification that the person is not at the facility where the work is being done.

c) An attempt to contact the person, wherever he or she is, to inform him or her that the lock will be removed.

d) A method to guarantee that the person is informed, before returning to work at that facility, that his or her lock/tag has been removed.

7.4.2.6 Lockout/tagout permit

Some work requires rigid lockout/tagout control of the type that should not be the responsibility of the employee alone. Lockout/tagouts of this nature should be secured by a formal permit. This more formal approach is called a *documented lockout/tagout*. Typically, this type of lockout/tagout would be used on

those types of jobs that are not simple and easily understood. Electrical work performed on medium- and high-voltage circuits is a good example. It would also include work on equipment that requires a complex lockout/tagout due to multiple sources of electrical energy. Also included would be jobs that require work inside of grinding mills, choppers, fan housings, ovens, storage tanks and silos, and similar situations in which personnel are in a position that unexpected equipment start-up would, without question, result in serious injury or death. In general, the documented lockout/tagout shall be used except when the conditions given in 29CFR1910.147 for a nondocumented lockout/tagout allow an exception.

No specific permit system can be recommended as good practice in all circumstances. A workable permit system can be developed only on an individual basis at the plant level by personnel intimately familiar with plant operations. Certain requirements that represent good practice in one plant might be inadequate or unworkable in another plant with different problems and a different personnel structure.

One fundamental feature, however, should be incorporated into any permit system. It should be designed with checks and balances. Specific responsibility for a particular operation should be assigned to an individual without relieving others of the obligation to double-check the status of the lockout/tagout before proceeding with their own assigned steps in the process. The permit system, then, should be developed to duplicate and reinforce, rather than dilute, responsibility.

Every step in processing a lockout/tagout permit, from the initial request to the official closing, should be confirmed in writing on an official form. The permit form should include spaces for every person involved to indicate the times and dates when the paperwork was received and when the action was taken. Completion of each step should be acknowledged by the signature of the person responsible for taking the appropriate action. Every person involved in processing the permit should be held responsible for checking the paperwork referred to them to see that everything is in order before proceeding with their own step.

7.4.2.7 Temporary release of lockout/tagout permit

In general, the lockout/tagout procedure should require that the equipment covered by the lockout/tagout permit not be altered unless the entire permit is closed out. Some types of work, however, require that equipment be operated to determine if the job is completed properly. For example, an employee balancing a large fan might be required to enter the fan housing repeatedly to attach balance weights, and the fan might be operated after each attempt at balance to obtain a vibration reading.

In such cases, it is permitted to remove the lockout/tagout devices temporarily and then replace them without going through all of the paperwork and approvals again. The need for the temporary release should be documented in the initial paperwork. In addition, everyone on the job shall be made aware at the beginning of the job, in the job briefing, that a temporary release will be employed. The physical actions of a temporary release are the same as if persons were removing their lockout/tagout devices permanently. Those persons who have to return to working on that job after the temporary release shall reapply their lockout/tagout devices before resuming any work.

7.4.2.8 Use of up-to-date single-line diagrams

The single-line diagram is the road map of an electrical system, tracing the flow of power from source to load. It indicates points at which power is fed into the system and at which power can be disconnected. No complex lockout/tagout should ever be attempted without first consulting the appropriate single-line diagram.

Because capacitors and instrument transformers are not normally viewed as power sources, they can be easily overlooked when securing a lockout/tagout. Yet, they can impose lethal voltages on the electrical system. Special care should be taken in checking the single-line diagram for the presence and locations of capacitors and instrument transformers any time a lockout/tagout is secured for performing work on

electrical circuits. Additionally, automatic transfer switches can be especially hazardous, as the emergency/standby source (such as a diesel generator) may be connected in a remote location.

In every facility, some person or group should be designated to keep single-line drawings up-to-date and audited. The location of drawings should be known and openly accessible to the personnel who are planning and performing work requiring a lockout/tagout. Drawings posted in substations and other locations throughout the plant should not be relied upon because they are often out-of-date.

7.4.2.9 Hazardous energy control for mechanical equipment

The lockout/tagout of valves, hydraulic and pneumatic operators, and engine and turbine prime movers is generally considered mechanical, rather than electrical. Such equipment normally is locked and tagged out by mechanical maintenance personnel or operating personnel. Valves, however, might be electrically operated, and pneumatic and hydraulic circuits are almost always electrically powered and are often electrically controlled.

Because the purpose of a lockout/tagout program is to provide for the safety of all personnel, it is usually best to combine mechanical and electrical equipment on the same lockout/tagout permit. There may be cases, however, where it might be best to divorce the two. If different departments are responsible for mechanical and electrical lockout/tagouts, it is important to coordinate the two so that electrically operated valves and hydraulic and pneumatic circuits are effectively locked out and tagged as a team effort.

7.4.2.10 Making the system workable

A workable lockout/tagout program should make some distinctions between the essential and the desirable. Balance should be struck between two extremes. At one extreme, there is no formal hazardous energy control system, and everyone must look out for themselves and make their own rules. At the other extreme, there is a rigid system that requires a formal lockout/tagout permit to be in effect before any work is undertaken on any equipment. The former is clearly unthinkable and in violation of Federal law. The latter is not very practical or realistic.

Employee acceptance and respect are essential to the success of any lockout/tagout program. Imposing unrealistic requirements that are certain to be violated by employees, or ignored at the convenience of management, only fosters contempt for the entire system. A procedure should be developed that gives step-by-step instructions for implementing the program. The plant's current version of the lockout/tagout procedure cannot be violated. The program, however, should have a provision so that the procedure can be readily changed and revised when necessary. Copies of the latest revision to the lockout/tagout program should be issued to employees by identifying revision number and date. Training sessions on the changes should be held with all employees when changes are made. Superseded copies of the procedure should be collected or destroyed when the new version is issued.

The plant's lockout/tagout procedure should be developed with care, and a searching review of the procedure should be made periodically. Answers should be continually sought to the following questions:

- How might the procedure be improved?
- Are there loopholes that should be closed?
- Are all employees who are subject to exposure being adequately trained?
- Are there any requirements that are being tacitly ignored?
- If so, why are they being ignored?
- How can unrealistic requirements be modified to encourage compliance?
- Most importantly, does the procedure work?

7.4.2.11 Examples of poor hazardous energy control practices

The following items discuss some practices that were used in the past for safety control. These practices are *not* truly safe practices and should not be used today.

a) *Locking out a push-button, control switch, or other pilot device does not ensure that the circuit will remain de-energized.* A short circuit or ground in the control circuit can bypass the pilot device. Another employee might even engage the contactor or starter by hand. Unless the disconnecting means is opened and locked out, an employee should not place himself in a position where unexpected equipment start-up or energization might cause injury. This is specifically disallowed in 29CFR1910.333(b)(2)(ii)(B).

b) *Turning the handle of a disconnect switch to the "off" position does not ensure safety.* The switch linkage might be broken, leaving the switchblades engaged. Switchblades in the open position should be confirmed by visual inspection. The load side of the switch should also be checked with a voltage tester to verify that the outgoing circuit is de-energized, and that there is no backfeed.

c) *Removing and tagging fuses does not constitute a lockout/tagout.* A lockout/tagout device should be attached to the fuse clips in a manner such that no fuses can be inserted without removing the device. If fuses are contained in a drawout fuse block, the tag should be attached to the fuse panel, not to the drawout block. Special precautions shall be taken to prevent shock whenever energized fuse clips that are accessible to the touch must be tagged.

d) *Simply opening a power circuit breaker does not ensure safety.* Even if the control fuses are removed, the breaker can still be engaged with the manual operating mechanism. The switchgear must be racked away from the bus contacts and into the "fully disconnected" position, and the racking mechanism shall be locked and tagged.

7.4.2.12 Other points to consider

The following is a list of points to consider when drafting an electrical lockout/tagout program:

a) The plant's lockout/tagout program should consist of two parts. The first part should cover general considerations. The second part should cover specific procedures that apply to documented or nondocumented lockout/tagouts.

b) All crews are to use the same lockout/tagout system, whether they are contracted or in-house. All crews also must be trained in and familiar with the lockout/tagout procedures that are to be used.

c) Terms should be used in the same context in which they are used in the system. Definitions should be provided for *lockout/tagout*, *lockout/tagout program*, *lockout/tagout procedure*, *lockout/tagout permit*, *released*, *restored*, *locked out*, *tagged*, *disconnecting means/disconnect switch*, *qualified*, *authorized*, *affected*, and whatever other terms are appropriate in a particular facility.

d) No two crews working under different supervisors should be permitted to work under the same lockout/tagout permit. Each crew leader should secure a separate (redundant) permit.

e) Steps should be taken to eliminate the possibility that temporary grounding leads might be overlooked when energy is restored. Grounding leads should be issued only with a permit that identifies each set of leads by a distinctive number.

f) The lockout/tagout procedure should include detailed provisions for the lockout/tagout, grounding, and bleeding of capacitors and other stored energy devices.

g) The procedure should indicate that lockout/tagout alone does not necessarily indicate safety. All of the steps in establishing an electrically safe work condition should be applied.

h) Procedures for removing padlocks with a master key should be rigidly controlled. If the person who attached the padlock is absent from work, the steps in 7.4.2.5 shall be followed. If a time-card system exists in a facility, a suggested practice is to remove the employee's time card from the rack

and substitute an official card informing them that their clearance has been removed and that they are to report immediately to a designated supervisor for briefing.

i) Provisions should be made for transferring lockout/tagouts from one person to another for work that must carry over from one shift to the next. The lockout/tagout program should provide for a written transfer procedure.

7.4.3 Temporary personal protective grounding

Sometimes, additional measures are desirable to provide an extra margin of safety. Temporary personal protective grounds are used when working on de-energized electrical conductors to minimize the possibility of accidental re-energization from unexpected sources. Sometimes these are called *safety grounds* or *equipotential grounding.*

Induced voltages, capacitive recharging, and accidental contact with other circuits can occur. Depending on the electrical energy available, these occurrences could cause injury or death. More often, however, they only cause reflexive actions. For example, although most induced voltages will not normally cause serious injury themselves, they could cause a person to jump backward suddenly, possibly tripping against something or falling to the floor. Temporary protective grounding devices should be applied where such conditions might occur. Temporary personal protective grounds should be applied at possible points of re-energization. They can also be applied in such a way as to establish a zone of equipotential around a person. When temporary personal protective grounds are used, they shall be connected tightly, since they establish a deliberate fault point in the circuit. If unintentional current does somehow get onto the circuit, the grounds must stay connected securely until a protective device clears the circuit.

It is difficult to set firm criteria for when temporary personal protective grounds are needed. Blanket requirements are usually established. Many times, it is a decision made in the field by the person performing the work. When there is uncertainty about exposure, it is wise to add this extra protection. Many industrial facilities and utilities require temporary personal protective grounding for all aerial power line work and for all work on power systems over 600 V because of the increased exposure these systems often have due to their length and location. Temporary personal protective grounding can also be used as the additional safety measure required when hazardous electrical energy control must be performed using a tag only.

Temporary personal protective grounding devices should meet the specifications in ASTM F855 and should be sized for the maximum available current of any possible event. Temporary personal protective grounds should only be installed after all other conditions of an electrically safe work condition have been established. Because the unexpected can happen at any time, however, the installation and removal of temporary grounding devices should be performed, by procedure, as though the conductors are energized using appropriate live-line tools only.

When installed inside equipment enclosures, temporary grounds should be lengthy enough to extend outside of the equipment so that they can be easily seen. If they cannot extend out, they should be made highly visible. Brightly colored tapes are helpful identifiers. Once temporary grounds are installed, bare-hand work could be permitted.

All personal protective grounds must be removed prior to re-energization. Identification and accountability controls may be necessary on large construction or maintenance jobs. The installation and removal of these grounding devices can be controlled by permit in order to avoid re-energizing equipment into a faulted condition.

The integrity of personal protective grounds should be maintained through the use of periodic inspection and testing. It is a good idea to document this inspection and testing.

7.5 Working on or near equipment that is, or can become, energized

A person's first reaction to working on or near electrical conductors or circuit parts should be to determine how to put them into an electrically safe work condition as described in 7.4.1. Occasionally, however, this is not practical. In some cases, de-energizing safety-related equipment might cause an even greater hazard than exposure to electricity. In other cases, de-energizing equipment in a continuous process might cause functional operating problems or involve great cost. In such cases, serious thought should be given to why the equipment cannot be de-energized, and how the job can still be accomplished as safely as possible while energized. Essentially, the job can be done as safely as possible by personnel who have been trained, qualified, and authorized to use safe practices and appropriate PPE, tools, and test equipment. The following key points can be a safety checklist to determine whether or not one is ready to begin work.

a) Know the safe practices that are pertinent to the task that you will be performing.

b) A "permit for energized work" should be completed (see 7.4.3.). This permit should include the justification and management approval for working on or near electrical conductors or circuit parts while they are energized.

c) Follow existing procedures where they exist. If previously prepared procedures do not exist, prepare a temporary job plan or procedure.

d) Stop work and rethink the situation if procedures cannot be followed as written.

e) Be sure to perform an on-the-job hazard/risk analysis. (See 7.3.1 through 7.3.7.)

f) Know and maintain safe approach distances from exposed energized parts. (See 7.5.3.)

g) Obtain and use PPE for body parts that extend within the flash hazard distance and/or the shock hazard distance. (See Clause 8.)

h) The use of PPE and arc-rated clothing does not eliminate electrical hazards, it only minimizes the effects of those hazards.

i) Make sure a standby person is present and knows never to leave anyone alone while he or she is exposed to the electrical hazard.

The terms *working on* and *working near* have always been subject to a wide variety of interpretations. NFPA 70E clarified this point by reclassifying the terms to "working while exposed to electrical hazards." NFPA 70E-2009, Chapter 1, Article 100, defines the term *working on* (energized electrical conductors or circuit parts) as "Coming in contact with energized electrical conductors or circuit parts with the hands, feet, or other body parts, with tools, probes, or with test equipment, regardless of the personal protective equipment a person is wearing. There are two categories of 'working on': *Diagnostic (testing)* is taking readings or measurements of electrical equipment with approved test equipment that does not require making any physical change to the equipment; *repair* is any physical alteration of electrical equipment (such as making or tightening connections, removing or replacing components, etc.)."

The rewording to "working while exposed to electrical hazards" is in response to the need for clarifying and defining the term *working near*. A common example to illustrate the need for clarification would be a situation where there is a pad-mount transformer on the sidewalk next to an office building. Would the term "near" apply to everyone that walked on the sidewalk next to the transformer, thus requiring them to wear arc-rated PPE to enter the building?

Adding the clarifying statement "while exposed to electrical hazards" to the word *near* called for establishing a shock boundary at some distance away from the exposed energized parts and giving the boundary and the space within it specific identifiers, which coincides with a worker being exposed to electrical hazards. The outermost shock boundary was called the *limited approach boundary*. Only electrical safety-qualified persons are permitted to cross that boundary and work in the contained space. Unqualified persons are not allowed in this space unless the circuits and equipment have been placed in an electrically safe work condition. More will be discussed about approach boundaries and spaces in 7.5.3.

Another term that is difficult to define is *hot work*. It is old slang terminology for working on or near energized electrical conductors or circuit parts. There has been an attempt to discontinue the use of that term in the electrical business because it is too subject to interpretation, and it has so many meanings in other types of work. The term hot work could be interpreted to mean only working on energized conductors. Then again, it could be interpreted to mean working near, as well. Also, in general types of work, the term hot work means working on or near something that is thermally hot. In fire protection language, hot work is using devices and equipment that generate open flames, sparks, or excessive heat that could trigger a fire in an undesirable place. In radiological language, hot work means work with or near highly radioactive material. So, even though it is easier to say hot work, the term should be avoided. "Working on or near energized electrical conductors or circuit parts" is much more descriptive of the true hazard.

7.5.1 Overhead lines

Statistics on accidental electrocution show that quite a few of them involve work on or near overhead electric lines. Work on overhead lines is only to be done by qualified electrical lineworkers. Many times, due to the need to maintain service continuity, the lines are kept energized while work is being performed on them. Lineworkers must be well trained to perform such tasks using safe practices, appropriate PPE, and insulated tools.

When planning for work on overhead lines, however, one should always try to make the safest choice, which is to put the lines in an electrically safe work condition. Grounding the lines to create an equipotential zone within which a lineworker's safety risk is minimized is advisable while working on overhead lines.

Work on or near overhead lines requires unique safety analysis because of the following:

a) The overhead lines can change position due to wind or other disturbances.
b) A person working on the lines is not usually in the most stable position.
c) The voltages and energy levels involved with overhead lines are often large.

Working near overhead lines, or near vehicles and equipment that could contact overhead lines, requires electrical safety training even for nonelectrical personnel. (See 7.5.2.)

The NESC is a key document that gives significant detail regarding the safety rules for the installation and maintenance of overhead electric supply and communication lines. NFPA 70E-2009 also mentions safety around overhead lines in Chapter 1, Article 130.

The OSHA regulations that cover work on and near overhead electric lines are 29CFR1910.269 and 29CFR1910.333 for general industry, and 29CFR1926.955 for the construction industry.

7.5.2 Vehicles and mechanical equipment

NFPA 70E discusses requirements for the use of vehicles and mechanical equipment in the vicinity of overhead lines. To paraphrase, this document says that where it can be reasonably anticipated that parts of any vehicle or mechanical equipment structure will be elevated near energized overhead lines, they shall be operated so that the limited approach boundary distance [given in Table 130.2(C) in NFPA 70E-2009, Chapter 1, Article 130] is maintained.

Electrical workers and others who are working near energized overhead electric lines should use insulated bucket trucks and other equipment that have insulated booms.

Many times, it is necessary to perform work near overhead lines, but not on them. This kind of work is done using mobile mechanical equipment that is capable of movement in an elevated position, such as cranes, derricks, aerial lifts, and dump trucks. In these cases, both the person operating the equipment and persons on the ground can be exposed to an electrical hazard. Persons on the ground should not touch the vehicle. Persons at ground level should not stand at or near the point at which the elevated equipment is connected to a grounding electrode.

OSHA regulation 29CFR1910.333 addresses vehicles and mechanical equipment in the vicinity of overhead lines. OSHA 29CFR1926, Subpart V, also covers this situation for the construction industry.

The dimensions for clearances from overhead lines are given in several of the documents mentioned above. The NFPA 70E Committee, however, is attempting to update requirements regarding safe approach distances, making them uniform and more easily understood. (See 7.5.3.)

7.5.3 Approach distances

In the past, approach distances to exposed energized electrical conductors were based on arc-over distance plus a generous safety factor. Today it is recognized that approach distances should take into account the flash hazard. Depending upon the amount of available fault energy, the safe limit of approach to protect against flash and blast could be further away than the distance necessary for shock protection.

Tables of approach distances from various sources in the past have given a variety of distances that were close to each other, but were not standardized. NFPA 70E-2009 has established a table that takes into account the shock hazards for both fixed equipment and equipment in which inadvertent movement is a factor. This table is located in Chapter 1, Article 130, of that document. NFPA 70E also provides tables for the selection of arc-flash clothing and PPE, also located in Article 130. Annex C contains a figure that shows the limits of approach and names the boundaries and spaces in the area that have in the past been identified as "near."

IEEE Std 1584-2002 provides two spreadsheets that provide calculation estimates in order to determine arc-flash limits for approach distances that have the possibility of the onset of a second-degree burn, or if closer approach is needed, the PPE necessary to avoid burns. NFPA 70E-2009, Annex D, also provides a calculation estimate that can be used under engineering supervision to determine the minimum approach distance to protect against flash.

Other tables and discussions of approach distances can be found in the NESC and OSHA regulations. At the time of this writing, however, those documents do not consider flash protection. As was mentioned in 4.2.2, several studies, tests, and technical papers are being written on the subject of the flash hazard. One of their objectives is to better define safe approach distances.

7.5.4 Switching operations

A major cause of personnel injury at industrial plants is the malfunction that occurs during the closing or opening of some types of switches or circuit breakers. Normally, switching operations are routine and everything goes smoothly. Every once in a while, however, something goes wrong. Some part of the electrical switchgear might come loose, a breaker compartment might be out of alignment due to wear, or interlocks might fail and load current might be initiated or interrupted. Also, due to increasing fault capacity in electrical power supply systems, some older, existing switches and breakers may not have sufficient capability to withstand possible fault currents. The failure of a circuit breaker or fuse due to insufficient interrupting rating can create a serious safety hazard. If a fault occurs that exceeds the interrupting rating of the circuit breaker or fuse, the circuit breaker or fuse could rupture, causing a blast that can violently open the cover or door of the enclosure. Such an event is almost always unexpected. If a

person is operating a circuit breaker or fused switch, the person performing the switching should always be prepared for the unexpected.

A well-defined procedure for closing switches and circuit breakers can help minimize the personnel hazards involved in this operation. For example, the method should state that no one should ever be allowed to stand directly in front of a switch or circuit breaker while it is being operated. The person performing the switching should stand off to the side of the switch or breaker enclosure, keeping the head and body as far as possible from the enclosure door. While performing the switching, the face should be protected and the arm should be extended as much as possible to operate the switch. The use of an arc-rated shirt or coverall or even an arc-rated flash suit, should be considered, depending upon the required position of the person performing the switching, the available fault current, and whether or not trouble is suspected. Operation of the switch should be firm and quick; never an indecisive “teasing.” Breakers and switches should be operated only with their doors and covers securely in place. Using this systematic method, if an electrical explosion does occur, a person’s exposure to injury is reduced to a minimum.

Local procedures should be developed covering the safety of operation of electrical equipment. Most of the information that is required to create a procedure can be obtained from the manufacturers’ literature or by asking the manufacturer for a recommendation.

Proper operation is important for electrical safety because when things do not happen as expected, injuries or fatalities are more likely to occur. See more about the operation of electrical equipment in Clause 9 of this standard and IEEE Std 3007.1™-2010 [B29].

7.5.5 Penetrating into “unknown” space

A task that is encountered often, not only by electrical personnel, but by many employees in different crafts, is that of penetrating a wall, drilling into a floor, excavating the earth, or otherwise penetrating into a space containing possible unknown hazards. Many shocks, injuries, and quite a few deaths have resulted from performing such tasks without doing a thorough job of investigating what might possibly be in that space. These unknown areas might contain electric or natural gas lines. When penetrating into unknown spaces, one should assume that there could be electric wires hidden in the space and, therefore, that extra precautions should be taken. A work authorization document should be required. (See 7.3.2.) This document should force some planning before work actually starts. Other precautions that should be considered include checking the facility’s structural, electrical, and underground line drawings; using detection equipment; using appropriate PPE; and using grounding devices on conductive tools and equipment. In some cases in which high-energy lines are suspected, arc-flash protection may be warranted. If the penetration is underground, one should be on the lookout for underground warning tapes or other indicators after the digging begins.

7.5.6 Other safe practices

There are many other safe practices mentioned in NFPA 70E. Since most of them have become requirements of law through the OSHA regulations, NFPA 70E should be read and understood thoroughly. The following is an overview of some of those practices:

a) Employees should be alert while exposed to electrical hazards. Supervisors should not allow them to work under such conditions if their alertness appears to be impaired, even temporarily.

b) Employees should not be permitted to work while exposed to electrical hazards unless they have adequate illumination on the work area. They should also be instructed not to work around obstructions or work in a manner in which their visibility is impaired. They should not reach blindly into an area that might contain exposed energized parts.

c) Employees working in a cramped or tight space that contains exposed energized parts are required to use protective shields, barriers, or insulating materials to avoid inadvertent contact with such parts. Doors and hinged panels shall be secured so that they cannot swing into an employee and bump him or her into the exposed parts.

d) Conductive materials and equipment, in an area where there might be exposed energized parts, shall be handled in such a manner that contact with the energized parts will be prevented.

e) Portable ladders used in areas with exposed energized parts shall have nonconductive side rails.

f) Safe practices also include using protective equipment, using tools properly, and employing other miscellaneous methods. These subjects are covered in Clause 8.

g) Proper use of electrical equipment is also a safe practice and is discussed in Clause 9.

8. Protective equipment, tools, and methods

8.1 Introduction

Electrical protective equipment serves to eliminate or reduce hazard severity, reduce the likelihood of an accident given that a hazard exists, and reduce the severity of the injury if an accident occurs. Historically, electrical protective clothing and conductor guarding were first applied to the prevention of electric shock injuries. In the 1970s, users and manufacturers began recognizing and addressing the electric arc hazard. In the early 1990s, OSHA regulations and NFPA standards began incorporating specific requirements to protect personnel from electric arc burns.

The selection of personnel protective equipment (PPE) should be determined by a hazard analysis that determines the hazard severity and the parts of the body that could be exposed to the hazard. All body parts exposed to electrical hazards shall be protected as a last line of defense from personal injury.

In addition to protective clothing, managing systems can be designed to augment the reduction of hazard exposure. Properly designed labeling and documentation practices serve to communicate and inform people of hazard presence and potential. Work practices can be engineered to reduce the potential for accident and injury.

The American National Standards Institute (ANSI) and the American Society for Testing and Materials (ASTM) standards that pertain to the selection, care, and use of protective clothing, equipment, and tools are summarized in Tables 130.7(C)(8) and 130.7(F) of NFPA 70E-2009.

8.2 Personal protective equipment

Voltage-rated rubber gloves provide protection from hand contact with an energized source. Gloves are available in various voltage classes and with different cuff lengths. These gloves shall be used, inspected, and maintained to verify their protective integrity. Leather protectors shall be used to minimize damage during use. Gloves shall be stored to prevent damage from sunlight, abuse, and contamination. They should be carefully visually inspected. The care, inspection, and testing of rubber gloves are detailed in ASTM F 496 [B5] and ASTM F 1236 [B6]. ASTM D120-2 [B4] provides six different voltage classifications, as shown in Table 4:

Table 4—Class and voltage rating for rubber insulating gloves

Class	AC proof test voltage (V)	AC maximum use voltage (V)
00	1 000	500
0	5 000	1 000
1	10 000	7 500
2	20 000	17 000
3	30 000	26 500
4	40 000	36 000

Most arc burns are incurred by personnel who are working close to energized parts and operating or servicing energized equipment that has available fault current sufficient to produce an explosive arc. Switchgear operation, hook-stick operation of fuses, or the repair or testing of components are typical activities that place people in such vulnerable positions. Suitable protection means that when the potential for severe faults is present include the following:

a) Leather gauntlet gloves or arc-rated *flame resistant* (FR) glove
b) Ultraviolet (UV)-rated safety glasses
c) Nonconductive hard hat
d) Hearing protection (ear canal inserts)
e) Arc-rated balaclava (sock hood)
f) Arc-rated face shield and/or arc-rated hood
g) Arc-rated clothing or covering over flammable, non-melting clothes or arc-rated daily wear
h) Greater separation of personnel by longer live-line tools and shields
i) Prohibition of work within the hazardous burn distances of live parts by requiring the de-energizing of these parts before work is started

Using arc-rated clothing, face shields and hoods, and leather gloves has improved the safety of the operators and has reduced the severity of injuries from explosive faults and electric arcs during the operation and servicing of electrical switchgear. The selection of arc-flash protective clothing is dependent on the severity of potential faults, the amount of incident energy that could be transferred to the person exposed, and the thermal characteristics of the protective clothing. NFPA 70E provides a method for determining fault severity. For guidance on the selection of PPE, refer to NFPA 70E-2009, Article 130.

8.3 Other protective equipment

8.3.1 Rubber blankets

Insulating rubber blankets can be draped around energized conductors or equipment to provide a temporary insulating system. They were originally designed for utility open lines, but can be used in some industrial applications. Various clothespin-like clamps can be used to hold these devices in place. They have the same voltage classification as rubber gloves and should be inspected for holes before use. When using blankets

on metal-enclosed switchgear, magnetic holding blocks can also be used. Outside influences should be considered when protecting the integrity of the electrical insulation.

8.3.2 Insulated tools and handling equipment

Insulated tools, ladders, and live-line tools provide protection from both shock and arc-flash burns. The tools and devices shall be rated for the voltage with which they may come in contact, and should be stored properly and inspected to maintain insulation integrity. Regular maintenance would also include cleaning, inspecting, and electrically testing live-line tools on a regularly scheduled basis. Double-insulated electric power tools should be inspected and repaired according to the manufacturers' directions to verify the double-insulation integrity.

8.3.3 Doors, covers, shields, guards, and barriers

Doors, covers, shields, guards, and barriers serve to prevent contact with, or limit approach to, energized electrical conductors and circuit parts. Their effectiveness in preventing unintentional contact is dependent upon the workers' understanding and conscious awareness of the guarded hazard. In situations in which equipment or circuits are isolated and locked-out in order to enable work on de-energized circuits, the doors, covers, shields, guards, and barriers that define the boundaries of the safe work area shall be understood. In addition to knowing what is locked-out, it is important to identify and communicate where energized sources may exist.

8.3.4 Ground fault circuit interrupters

Ground fault circuit interrupters (GFCI) sense when electric current exists in other than normal paths, such as through a person, and prevent serious injury by isolating power to the circuit within milliseconds. Although they were initially required only for use where portable tools, appliances, or equipment could be used in damp or wet locations, the expanded application of GFCIs offers a significant level of protection for any use of temporary extension cords or portable tools and equipment.

8.4 Protective methods

Administrative controls or standard approaches to common tasks serve to minimize variables that contribute to operating errors. These may address common maintenance tasks, equipment design and installation, system documentation, and job planning.

8.4.1 Grounding of equipment

The integrity of equipment grounding is essential to personnel safety. Grounding is discussed in more detail in 6.2.7 and 7.4.3. Grounding is a primary protective method for protecting people from shock hazards that could exist in poorly grounded or ungrounded metallic raceways, equipment housing, or enclosures. The design and installation of equipment grounding is detailed in Article 250 of the NEC.

8.4.2 Alerting techniques

Examples of protective systems that serve to warn personnel of impending hazards include the following:

a) Signs and placards
b) Fences and other physical barricades
c) Marking tape for underground lines
d) Attendants

8.4.3 Planning

Any work on or near energized electrical equipment has the potential for an incident that could result in serious injury or death, interruption of electric power, disruption of control systems, or damage to critical equipment. A risk analysis of the task to determine the accident potential and the consequences will help to make sure that the correct decisions are made to provide facility reliability and personnel safety. A good starting point for the prevention of incidents is to prohibit work on or near live parts by requiring the de-energizing of these parts before work is started. Working while exposed to electrical hazards should be managed as exceptions to the rule, rather than normal practice. Articles 120 and 130 of NFPA 70E-2009 provide guidance for managing this approach and for establishing an electrical safe work condition.

Job plans or task procedures provide means to enable recognition and management of hazards prior to the beginning of work. If the task is relatively simple and involves one person, then it may not be necessary for the plan or procedure to be written. If, however, it involves more than one person, more than one craft, or extends beyond more than one shift, then having a written plan to confirm the common understanding of all parties involved is a much better method. In such instances, it is desirable to develop, in advance, a detailed plan for performing each step of the work with minimal safety risk. Such plans are most useful if they are written out in complete detail, with all involved crafts agreeing on each step of the procedure. Whether the plan is a mental plan, a verbal plan between two people, or a detailed written plan involving many people, effective planning and communication to all involved will serve to achieve safe and error-free results. Guiding principles for effective planning are included in 6.5.

8.5 Drawings and other documentation

Drawings and other documentation are essential for identifying and communicating the information needed to plan and implement work on electrical systems with a high degree of safety for the people involved and reliability for the systems impacted. Additional information on drawings and documentation is included in 5.2.7, 6.2.5, and 7.4.2.8.

8.5.1 Safety electrical one-line diagrams

Safety one-line diagrams are made to show all the sources of electrical energy in an electrical power system. They are designed for the electrically safe operation of a power system only and should have the following characteristics:

a) *Clarity*. The drawings should be easy to read in poor lighting conditions. Clarity should have priority over geographical location. The reason for this drawing is safety, so the drawing shall be clear and legible.
b) *Correctness*. The safety electrical one-line diagram must be accurate and kept updated as changes are made to the electrical system. There should be a system in the organization to keep the drawing correct, and to issue it to people who are authorized to do switching. These people shall be trained in the proper switching procedures.
c) *Component identification*. All power system components should be clearly identified on the drawing, as well as on the components themselves. Components are such things as switches, circuit breakers, cables, transformers, substations, potential transformers, etc. The components shall have

only one identification and it should be consistent on both the drawing and the equipment itself. Engraved plastic signs or any means that do not fade with time or the effects of weathering are satisfactory. The identification signs should be large enough to be read at a distance and should not be painted over. They should be on all sides of the equipment being identified and placed where there can be no question that the component is indeed what the sign says it is. Any special warning, such as "This is not a load break device," is acceptable, as long as the procedures are not on the identification sign. The purpose of this sign is to identify a component of a power system; it is not a substitute for trained people or a procedure manual. Short, alphanumeric designations are better than operating names. Avoid geographical descriptions (e.g., what do you call the "north acid pump" when another pump is placed north of it?). Avoid changing designations.

d) *Up-to-date, legible, and accessible*. The control of the diagram should include the destruction of the outdated drawings. A framed drawing on the substation wall is an excellent idea, as long as it is kept current and is replaced when it becomes faded or illegible. Drawings do fade with time, and the drawing should be legible under poor lighting conditions. Drawings must be issued only to personnel that are authorized to have them. Unauthorized copies must be impounded and destroyed when they are found, as they will not be updated when the authorized copies are, and this could lead to misinformation and accidents.

8.5.2 Panelboard directories

Panelboard directories allow the identification of circuits during an emergency and assist in performing lockout/tagout operations. Maintaining the quality and accuracy of lighting and power panelboard directories should receive as much consideration as all other electrical distribution system diagrams. It is recommended to maintain a database containing all electrical panelboard directories at a facility or plant. A database provides an easy means for the engineer or operator to keep panelboard directories updated. It can also be used to calculate panelboard loading and balancing. The facility or plant engineer should perform periodic inspections of all power distribution and lighting panelboards to verify that (1) panelboard directories are present within the panelboard, and (2) panelboard directories are accurate.

8.5.3 Plot plans (location plan)

A plot-plan diagram is a necessary accompaniment to the one-line diagram for a complete description and mapping of the industrial and commercial electric distribution system. The system operators may be familiar with the location of the major components of the system, but total familiarity of circuit routing may not be available for some methods of circuit installation, particularly for installations that are out of view by normal observation methods.

Plot plans are important for a number of reasons, all of which could impact upon the operation of the industrial plant or commercial complex at some time. If a major catastrophe should occur, such as a fire or storm damage, a plot plan is a necessary tool if the distribution system is to be reconstructed. Expansion and rearrangement of an electrical distribution system could be extremely difficult without the knowledge of the location of existing system components. The plot plan can be important for identifying the proximity of electrical system components to other maintenance work that may be taking place.

8.6 Safety audits

An overview of why safety audits should be an integral part of the electrical safety program is found in 5.2.8. The general attributes of an effective audit are described as follows. One dictionary defines the term *audit* as "a formal examination and verification of financial accounts." The word, as used here, means the formal examination and verification of the safety program and practices for a specific power system or systems. The principal things that one should look for when conducting a safety audit are as follows:

a) *An operating one-line diagram*. A power system can only be operated or maintained with maximum safety if readily available drawings exist that show all the components of the power system. The drawing shall be correct, current, legible, and available only to those who operate or maintain the power system. An operating one-line diagram can be used in place of a safety electrical one-line diagram, if necessary. Some operating one-line diagrams have information that is not required to operate the power system. There is no problem with adding this engineering-type information, as long as it does not distract from the clarity of the drawing. It is essential that the equipment be legibly marked with its operating name, and that this name be the same as the name on the safety one-line diagram. There shall be only one name for a power system component. More than one name for a piece of equipment can lead to switching errors and should not occur.

b) *Trained people operating and maintaining the power system*. Even a simple task, such as inserting a circuit breaker in its cubicle, is hazardous if the person performing it does not know the correct procedure. Inexperienced or untrained people are usually a major cause of most electrical accidents. This becomes more and more critical as the voltage increases. Medium-voltage (1001 V to 69 000 V) equipment is much less forgiving than low-voltage (0 to 1000 V) equipment of switching or clearing errors.

c) *De-energized work procedures*. All conductors of electricity shall be considered energized until it has been proven that they are de-energized and grounded. This clearing procedure begins with the operation of all upstream and alternate power source until there is no way that power can reach the part of the power system that people are working on. Voltage-sensing equipment that is tested before and after it senses the voltage should be used to determine if the part of the power system to be worked on is de-energized.

d) *Energized electrical work procedures*. Written procedures should be developed for all energized electrical work. These procedures should include a step-by-step outline of the work to be performed, protective equipment to be used, and familiarity with emergency-service procurement if a problem does occur. It should be approved by the person requesting that the energized work be done.

e) *Grounding*. Electrical power equipment should be grounded. Larger equipment, such as transformers and medium-voltage switchgear, typically has “pigtails” of 4/0 or larger wire to a grounding system of rods and interconnecting wire. This system needs to be inspected for presence and condition. A periodic (not more than every five years) ground integrity test program should be in place and documented.

f) *Corrosion*. No electrical system is safe if its components are corroded. Simply looking at equipment for corrosion can indicate whether it is not safe for service.

g) *Maintenance practices*. There is a great deal of equipment in electrical systems that do not have to operate until there is an overcurrent condition in the system. Protective relays, circuit breakers, and fuses are examples of such equipment. These devices simply do not do anything until an overcurrent condition occurs, and then they have to work quickly and correctly. Because of this, these devices must be tested and maintained periodically in accordance with manufacturer’s instructions. In addition, short-circuit, coordination, and arc-flash studies should be a accomplished for power systems and reviewed periodically and updated when there are changes in the system that affect the results of the study.

h) *Switching procedures*. All switching should be performed with written orders by qualified personnel only. Non-load-interrupting equipment should be specially marked and its limitations should be adhered to in switching orders. All switching orders should be thoroughly reviewed and approved by all personnel that will be involved in the operation. See 7.5.4 and 7.5.6 for additional considerations. The following text is an example of a switching procedure that a facilities or plant engineer would create to single-end a double-ended indoor substation or set of switchgear. This example does not include lockout/tagout steps. Should a switching procedure require lockout/tagout, those steps should be called out in the procedure. It is the engineer’s responsibility to indicate and enforce proper lockout/tagout. Application of locks and tags is of course dependent on the operation being performed and whether or not personal safety is a factor once the equipment is set to its desired state (i.e., de-energized).

Master control cabinet

1) **LOCATE** master selector switch.
2) **SET** master selector switch to **MANUAL**.
3) **VERIFY** "SWBD NOT IN AUTO" indicator light is **FLASHING RED**.
4) **SILENCE** audible alarm.

Tie cubicle

5) **LOCATE** **TIE** circuit breaker control switch.
6) **SET** control switch to **CLOSE**.
7) **VERIFY** **TIE** circuit breaker is **CLOSED**.
8) **VERIFY** **RED** status indicator light is **ON**.

Main circuit breaker cubicle

9) **LOCATE** **MAIN** circuit breaker control switch.
10) **SET** control switch to **TRIP**.
11) **VERIFY** **MAIN** circuit breaker is **OPEN**.
12) **VERIFY** **GREEN** status indicator light is **ON**.

A switching procedure should be created by the facility or plant engineer and reviewed at least one time prior to execution of the procedure to verify that the procedure is correct, and to confirm that everyone that will be involved is familiar and, most importantly, comfortable with the procedure. Another electrically qualified person who is familiar with the system should review the written procedure before it is implemented to confirm it is accurate. Typically, the engineer will assign an operator to call out the steps in the procedure and another operator(s) to actually switch or operate the equipment. Each step should be checked off and time stamped to allow for tracking purposes and the date of the operation should be recorded on the procedure. It is also helpful to include a one-line diagram of the system under operation to make is easier for the operators to understand the work being performed. Always indicate what safety PPE is required to be used by the operators. If temporary safety grounds or ground-and-test devices are required, the procedure should indicate how and where to apply the equipment.

8.6.1 Safety audit checklist

Table 5 shows an example of a safety audit checklist. This checklist provides an assessment of the minimum requirements needed to safely operate and maintain electric power systems.

Table 5—Example safety audit checklist

Safety audit requirement	YES	NO
One-line diagram exists		
One-line diagram is legible		
One-line diagram is correct		
All persons who operate the power system have easy access to the current one-line diagram		
Equipment is labeled correctly, legibly, and in accordance with the one-line diagram		
Persons who operate/maintain electrical equipment are trained for the voltage-class equipment they operate/maintain		
Working with de-energized equipment procedures exist and are followed		
Working with live equipment procedures exist and are followed		
Equipment is grounded properly		
Safety grounding equipment, PPE, and working tools (i.e., hot sticks, voltage testers) have been calibrated and tested		
Ground system is tested periodically		
Electrical equipment is free from corrosion		
Proper maintenance practices are followed, especially for fault-protection equipment		
Recent (less than five years old) coordination study exists, and overcurrent devices are calibrated to the setting recommended		
Up-to-date arc-flash hazard assessment is complete, equipment is labeled, and employees are aware of the hazard		
Power system is resistance grounded		
Written switching orders are reviewed and used		

8.7 Safety morale and culture

With all of the possible physical means available for working and operating with maximum safety, good results will not be attained unless both workers and their supervisors believe in safety and work at it all the time, contributing to a positive safety culture within the organization. Some may assume the philosophy that “the other guys need safety, but not me; I’m good enough that I don’t make mistakes.” Such attitudes can be overcome by constant reminders of the critical importance of safety. Posters, meetings, positive peer interaction, and safety instructions, along with specific technical instructions on each job, are a few methods that should be used.

Working safely is a condition of employment and a basic responsibility of every employee. This responsibility is the basis for most of our safety standards and rules. “Do it safely, or don’t do it.”

All too frequently, it is the top management that needs to be convinced that safety must be a part of each job, even though it may not be particularly expedient. This is a difficult problem to overcome; however, if safety does not start at the top, it can never precipitate to the bottom. Just as product quality reflects management policy, accident rates reflect management’s outlook toward personnel safety. Hence, with safety, it is obligatory to start at the top.

Always make sure there is enough in the training budget for continual safety training. Training and reviewing case studies is the single most important part of overall safety compliance at a facility or workplace. Far too often, managers may skip safety training due to budgetary constraints. This usually

happens to supervisors and engineers that are responsible for enforcing safety and conducting operating procedures. All personnel involved in working on or around electrical power systems should be properly and continually trained in electrical safety. Training can be expensive, but is very necessary for personnel safety and operational reliability.

9. Safety of use of electrical equipment

9.1 Introduction

In addition to the guidance provided in previous clauses, some helpful tips are provided here for the operation and use of common electrical equipment.

Portable electrical tools, temporary extension cords, and testing instruments are commonly used in any facility. The safety of use of these devices and equipment is dependent upon the users knowledge of both the task and specific equipment to be used, the integrity of facility grounding and protective systems (including the use of GFCIs), and the systems in place to manage the inspection and maintenance of portable tools and equipment.

The operation of distribution, utilization, and control equipment is often performed by people without an in-depth knowledge of the electrical characteristics of the equipment. They should, however, be knowledgeable of the hazards involved in operating the equipment.

9.2 Portable electrical equipment

Portable tools, equipment, and appliances potentially expose everyone to electrical hazards in the workplace. The safety of their use is dependent on both mechanical and electrical integrity, coupled with the users' awareness of potential defects. Considerations for the safe use of portable equipment include the following:

a) Cords and extension cords should provide an intact ground conductor from the building permanent wiring to the portable tool or equipment.
b) GFCIs provide a high degree of protection from electric shock and should be applied where tools and portable equipment are used in potentially damp environments.
c) Portable cords, tools, and equipment should be maintained in a safe condition.
d) Portable cords, tools, and equipment should be inspected before each use.

Before taking any electrical tool or device into a classified area, the consequences of an unintentional arc or spark should be addressed. If the device is rated for use in the classified area, consideration should be given to confirm that the safety integrity is intact. If the device is not rated for use, then it shall be managed as a potential ignition source.

9.3 Test instruments and equipment

Test instruments are commonly used for verifying the absence or presence of voltage, for troubleshooting, and for obtaining diagnostic information. Their use involves working while exposed to electrical hazards. The following are some considerations in managing the selection and use of test instruments and equipment:

a) Consider voltage test instruments as personal safety equipment rather than tools. These are the instruments that are used to determine whether or not a conductor is lethal or safe to touch. Treating them as safety equipment implies a higher level of attention and control.

b) Only use meters that are rated for industrial applications.

c) Minimize the number of manufacturers and models used in a facility.

As a minimum, instruments should meet the requirements of UL 61010-1 [B40] provides specific training for each model of the instrument. Each instrument has unique features, and even experienced personnel may be unfamiliar with subtle differences among similar models and styles.

d) Never use a damaged test lead or meter. Inspect leads for insulation damage or exposed metal before use. Never use a meter with obvious defects (cracked case, broken switch, water entry, etc.).

e) Reduce the risk of accidental contact by using leads with shrouded connectors and finger guards, and meters with recessed jacks. Consider the need for insulated gloves.

f) The high-voltage (typically 40 kV) accessory probes for meters that are available from most manufacturers are for low-energy electronic circuits and not high-energy power circuits.

g) For personal safety, *always* test the meter on a known energized low-energy circuit (for example, 120 V general purpose outlet) both before and after making voltage checks. This verifies proper meter performance (battery, fuses, etc.).

h) Implement a “test before touch” program for all those that have a need to use a voltage test instrument

9.4 Facilities infrastructure (power and light circuits)

No matter how experienced and knowledgeable personnel are, the person is the imperfect entity in the interaction between people and equipment. It is essential that deliberate attention be given to the planning and execution of switching operations, as it can compensate for deficiencies in knowledge or experience, distractions, and errors in judgment for any number of reasons. Switching activity that is performed in haste without a well-developed plan can be disastrous—both in terms of safety to personnel and the continuity of power to operations.

A well written procedure has the following features:

— Concisely and accurately describes the goal of the operation
— Identifies unusual conditions
— Provides a logical sequence
— Accurately identifies equipment to be operated, including placement of tags and/or locks
— Identifies vulnerable situations, including body position to minimize risk and PPE to minimize injury if an accident occurs
— Is reviewed by more than one knowledgeable person
— Is reviewed, modified, and reviewed again if things do not go as planned

More than one person should be responsible for switching activity. Each step should be stated and then repeated for verification to verify that the operation performed is correct and in sequence.

Annex A

(informative)

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